The Best Practicable Environmental Option for Paper Waste Management in Geographically Isolated Communities

Thesis

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PhD Thesis

The Best Practicable Environmental Option for Paper Waste Management in Geographically Isolated Communities.

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Abstract

Waste management generally, and paper waste specifically, are important issues. The problems finding suitable landfill sites and the legislative and environmental needs for alternatives to landfill make research into this field important. Isolated communities have specific issues related to the treatment of waste. Available sites for landfill are limited, the community is often economically dependent on tourism and local alternatives to landfill are limited, whilst transport across the barrier is expensive.

The aims of the research were to find the Best Practicable Environmental Option (BPEO) for paper waste management in isolated communities and to produce a tool that could be used by other areas to assess their own paper waste management practices.

During this research, three geographically isolated areas were chosen as study areas and the financial, environmental and legislative aspects of the current household waste management systems were examined. A financial model was produced and used in the case study areas. The environmental emissions were modelled by the use of WRATE, a Life Cycle Analysis programme developed by the Environment Agency for England and Wales. The financial, legislative and environmental impacts social factors of the six scenarios were examined by a Multi-Criteria Decision Analysis workshop consisting of residents from one of the case study areas.

The conclusions of the research were that:

- MCDA can be used to combine LCA, financial, legislative and social information to assist in determining BPEO for managing waste in isolated communities,
- The use of the MCDA panel allowed the local community to be involved in the decision-making process,
- Isolated communities have specific issues in regard to waste management,
- The research tool was valuable in finding the most sustainable paper waste management solution for the area,
- Local solutions are to be preferred financially, environmentally and socially although local or national taxes can distort the financial position.

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Glossary of terms

Acidification: *The problem of acidification is caused by acid depositions which originate from anthropogenic emissions of the three main pollutants: sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3). Acid depositions have a negative impact on water, forests, and soil. They cause defoliation and weakening of trees. Changes in soil and water pH have a harmful effect on soil and aquatic organisms. Damage is also visible on man-made structures, such as limestone and marble buildings and monuments. The main sources of emissions of acidifying substances are coal and other fossil fuel combustion used for energy production and transport, as well as use of animal manure in agriculture (Central European University 1999).*

Aquatic eco-toxicity: *This is the negative effect of emissions to water on the aquatic organisms in the ecosystem.*

Best Practicable Environmental Option (BPEO): *'The outcome of a systematic and consultative decision-making procedure which emphasises the protection and conservation of the environment across land, air and water .... a procedure which establishes for a given set of objectives the option that provides the most benefits or the least damage to the environment as a whole, at acceptable cost, in the long-term as well as the short-term (Royal Commission on Environmental Pollution, 1995).*

Biodegradable Municipal Waste (BMW): *The component of Municipal Solid Waste capable of being degraded by microbial action. Biodegradable Municipal Waste includes paper and card, food and garden waste and a proportion of other wastes, such as textiles.*

Climate change: *The United Nations Framework Convention on Climate Change (UNFCCC 2011) defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods".*

Cost-Benefit Analysis (CBA): *A technique to evaluate the social costs and benefits of investment projects to help decide whether or not such projects should be undertaken (Porteous 2008)*

Eutrophication: *Eutrophication is the process whereby plant nutrients are added to the natural environment, especially nitrogen and phosphorous, leading to changes in plant and animal populations and a degradation of the natural habitat (Cloern 2007).*

Externalities: *Environmental externalities refer to the economic concept of uncompensated environmental effects of production and consumption that affect consumer utility and enterprise cost outside the market mechanism. As a consequence of negative externalities, private costs of production tend to be lower than its "social" cost. It is the aim of the "polluter/user-pays" principle to prompt households and enterprises to internalise externalities in their plans and budgets (OECD 2011).*

Human toxicity: *The negative effects of emissions to air, soil and water on human health.*

Integrated waste management (IWM): *Integrated Waste Management takes an overall approach to the management of the complete waste stream and involves the use of a range of different treatment options.*

Municipal Solid Waste (MSW): *Waste from households, as well as other waste which, because of its nature or composition, is similar to waste from households (European Commission, 1993). The waste is in either solid or semisolid form and generally excludes industrial hazardous wastes.*

Multi-Criteria Decision Analysis (MCDA): *An assessment tool aimed at incorporating the social aspects of waste management into decision-making, with a key feature being the judgement of the decision-making panel in measuring and valuing various options.*

Resource depletion: *Depletion of renewable resources, above the sustainable level of the resource stock; for non-renewable resources, the quantity of resources extracted (OECD 2011).*

SimaPro: *Developed by PRé Consultants, a privately owned company registered with the Dutch Chamber of Commerce (Amersfoort). SimaPro has been widely used for LCA and includes several inventory databases. Developed as a general LCA tool, rather than specific to waste management.*

WRATE: *WRATE (Waste and Resources Assessment Tool for the Environment) software compares the environmental impacts of different municipal waste management systems. WRATE uses life cycle assessment to include the resources used, waste transportation and operation of waste management processes with their environmental costs and benefits. WRATE calculates the potential impacts of all stages in the collection, management and processing of municipal waste. The calculation takes account of the infrastructure and its operation as well as any benefits associated with materials recycling and energy recovery. Users specify the waste streams to be managed (residual household waste, kerbside recyclables, civic amenity waste and street sweepings) and their composition (paper, plastic, textile, glass).The user then defines the way the waste is managed in the graphical user interface (GUI) - including the collection containers, vehicles, collection round distances, intermediate transport and final recovery or disposal. Each waste fraction has been analysed for its chemical and physical properties. WRATE models these fractions according to the way the user manages the waste and calculates how emissions and heat/power recovery affect the outcomes.*

Chapter 1 Introduction

1.1 Background

The average UK household produces around 1.04 tonnes of domestic waste a year giving a total of around 32.5 million tonnes per year (Defra 2011). Between 20 and 30% of this consists of paper (Defra 2010) giving a total of 6.5 – 9.75 million tonnes a year of waste paper. In addition, the commercial sector produces approximately 12 million tonnes of paper a year (Defra 2010).

If it is landfilled along with other biodegradable materials, paper degrades over time producing leachate and the greenhouse gases CO_2 and methane. Whilst much of the landfill gas can be captured and burned to produce useful energy, some does escape and it is estimated that landfills accounted for 49% of the UK's methane emissions in 2007 (AEA Technology 2010). To reduce the reliance on landfills, a number of measures have been implemented at both the national and European level. The key measures being:

- The waste hierarchy, which places waste management options in the following order (most preferable first): reducing waste; reusing waste; recovery (recycling, composting, energy recovery) and then landfill as a last option.
- The landfill tax of £56 per tonne (for 2011-12);
- The Landfill Directive which requires a substantial reduction in the amount of biodegradable municipal waste (BMW) being landfilled; more specifically by 2015 to 50% (by weight) of that produced in 1995 and by 2020 to 35% (by weight) of that produced in 1995.
- Targets to recycle 50% of household waste and recover 75% of municipal waste by 2020 (HMSO 2007). These targets apply to England, but similar targets have been set by the devolved administrations.
- Targets for the UK to recycle 69.5% of paper packaging waste in 2011 and 2012 (Defra 2011).

The principle of "Best Practicable Environmental Option" (BPEO) is enshrined in national legislation (for example, HMSO (2007), SEPA 2003) and has to be applied when planning and implementing waste management strategies. England's national waste strategy (HMSO 2007) specifically states that the waste hierarchy can be overridden if a BPEO assessment shows that it is preferable to adopt technologies that are lower down the hierarchy; for example recovery rather than recycling.

The most widely accepted definition of BPEO is that produced by the Royal Commission on Environmental Pollution in its 12th report (HMSO 1988) which states that BPEO is

> *"the outcome of a systematic and consultative decision-making procedure which emphasises the protection and conservation of the environment across land, air and water,.....a procedure which establishes, for a given set of objectives, the option that provides the most benefits or the least damage to the environment as a whole, at acceptable cost, in the long term as well as the short term"*

The BPEO process should take into consideration the environmental and economic factors of waste management and the need for a 'systematic and consultative decision-making procedure' as well as encouraging the inclusion of social factors such as public awareness and concern, human health and stakeholders' concerns.

1.2 Isolated communities and waste

There is no universal definition of isolated communities, so for the purposes of this thesis, isolated communities will be defined as areas which are separated from other conurbations by geographical barriers, such as water, mountain ranges, or large rural distances. The definition will include the added problems such areas have with waste disposal; the limited areas for landfill sites; limited markets for disposable waste, so that recycling plants are generally situated across the geographical barrier; the need to conserve the natural and cultural environment for tourism and the local community; the added economic cost of transporting wastes across the geographical barrier; the limited funding available for wastes management in small, isolated areas, with a limited resident population. It should be noted that for some communities, the distances the geographical barriers cause can be quite small. In particular, the Isle of Wight is only 4.8 km from the English mainland but the time and cost implications of crossing the Solent mean that the island shares many of the features of more obviously isolated communities such as the Channel Islands.

Waste management is a particular problem in isolated communities. Many of these communities cover a small area with rigid boundaries (such as sea or mountain ranges) and have limited space for waste management activities (especially landfill). Furthermore, isolated communities are often further restricted in the availability of waste management sites due to the presence of significant areas being of particular scientific, historical, cultural or amenity value. For some isolated communities it may be possible to "export" the waste to another community or to the mainland, but this has significant financial costs. The pressures on waste disposal capacity that are also being faced by mainland communities may place further limits on this option.

The relatively small quantities of waste produced in these communities mean that the waste management systems need to be of smaller scale, which often leads to higher costs of waste management processes.

The above problems apply to the non-recyclable "residual waste" but also to recyclable components. Isolated communities tend not to have locally based industries such as glass works, paper mills and metal smelters that normally provide the market for materials recovered from waste. Exporting these materials can present significant costs. One possible exception to the lack of local markets for recycled products is compost produced from garden waste (and food waste if the composting system meets the appropriate national standards). Generally speaking markets can be found, if only for low-grade uses such as use by landscaping and building contractors. After kitchen and garden waste, paper is the main biodegradable fraction of household waste; therefore managing paper waste is the most significant issue when it comes to reducing waste management related greenhouse gas emissions in isolated communities.

1.3 Outline of thesis

This thesis presents a programme of research carried out to determine the financial, environmental and social factors affecting paper waste management decision-making in a number of isolated communities using the Isle of Wight, Shetland and Nordfjord (Norway) as case-study examples. These factors were combined in a novel decision support tool that was assessed using a group of Isle of Wight residents.

1.4 Chapter outline

Chapter 1 Introduction. Includes the background to the research, a definition of BPEO, a discussion of geographically isolated communities and waste management and an outline of the thesis.

Chapter 2 Literature review. The literature review was carried out to establish the current state of knowledge of this subject and therefore to identify the gaps that need to be covered by this research. European, UK and Norwegian waste legislation are considered to identify regulatory constraints on waste management. Previous research into isolated communities and waste management, the use of financial models, life cycle analysis and multi-criteria analysis in waste management and other literature which covered the use of BPEO as a working tool were also reviewed.

Chapter 3 Research questions and subsidiary questions. The reasons for choosing the main research question are discussed, together with six other subsidiary questions, which will be answered by the thesis.

Chapter 4 Methodology. The reasons for choosing the three case study areas used in the thesis are discussed. The Isle of Wight on the south coast of England, the Shetland Islands in the north of Scotland and Nordfjord on the west coast of Norway. Based on the literature review, this chapter also describes the tools used in the research to find the BPEO for paper waste management in isolated communities: a financial model based on real costs, an LCA examination of the environmental issues of paper waste management using WRATE and Multi-Criteria Decision Analysis with the inclusion of a workshop panel of isle of Wight residents to determine the importance of various social factors.

Chapter 5 Results and discussion - Case studies. This chapter discusses the three chosen case study areas, their geographical and demographic features and their current waste and paper waste management practices.

Chapter 6 Results and discussion – Financial model. This chapter discusses the results of research into the real costs of waste management. This includes the costs of collection, road transport, sea transport, gate fees and taxes for waste in the UK and in

Norway. All these costs are combined to assess the costs of current and theoretical paper waste management in the three case study areas.

Chapter 7 Results and discussion – Life Cycle Assessment of municipal waste management. With the use of the WRATE LCA model, this chapter reviews the environmental impacts of managing the whole household waste stream in the case study areas. Together with one mainland area, Portsmouth, (which is just inland from the Isle of Wight and was selected to provide a non-isolated comparison), the chapter gives a baseline for the research into paper waste in Chapter 8.
Chapter 8 Results and discussion – Life Cycle Assessment of paper waste management. In this chapter, WRATE is used to assess the environmental effects of current and theoretical paper waste management in the three case study areas.

Chapter 9 Results and discussion - Multi-Criteria Decision Analysis of paper waste management. This chapter considers the results of the MCDA panel workshop which used the legislative, financial and environmental results to select their BPEO for paper waste management on the Isle of Wight.

Chapter 10 Summary of the results of the financial, LCA and MCDA research. The results of the four previous chapters are summarised, compared and put into context.

Chapter 11 Review of results in relation to the research questions. This chapter considers the results in the context of the research questions posed in Chapter 3.

Chapter 12 Conclusions and recommendations. The various areas of the thesis are drawn together and conclusions from the research are stated. There are recommendations for further research into areas not covered by this thesis, which would expand and complement the findings of this research.

1.5 Aim and objectives

The overall objective of the research described in this thesis is to produce a decision tool to enable the Best Practicable Environmental Option (BPEO) for paper waste in isolated communities to be identified.

This will be achieved through the following objectives:

- To define the term isolated communities and to identify three geographically isolated areas for use in the case studies.
- To identify if these communities have any particular problems associated with paper waste management that are different from larger conurbations.
- To determine the cost of managing paper waste in these communities and identify costs particular to their isolated nature.
- To assess the environmental impacts of managing household waste and waste paper in the case study areas.
- To develop a multi-criteria decision analysis tool that combines and presents the above factors and allows non-expert community panels to be involved in the decision making process.
- To use, and review the effectiveness of, the tool with a panel of local residents in one of the case study areas.

Chapter 2 Literature Review

2.1 Introduction

The purpose of a literature review is to give background information to the thesis, examine whether the research has been done previously and also where the research fits into gaps in the current scientific knowledge. There are particular areas of research relevant to this thesis, which have been a part of the review.

As the research includes three case studies from different parts of Europe, the literature review includes the waste management legislation that governs the policies of these areas. The case study areas are from England, Scotland and Norway, so the review has also concentrated on the national waste management legislation from these three countries. The reasoning behind this choice is the need to investigate the legislative requirements for the areas, to see whether they are proactive or reactive to demands from the European Union and to see how this affects their choice of waste management options. The literature review goes on to investigate the previous use of tools and models in waste management. This was necessary to be able to decide upon the optimum tools to use in my own research. Finally, the review looked into previous research in geographically isolated areas and their particular problems with waste management. This background gave me a good basis for my own research.

2.2 European Legislation

The literature review concentrates on the legislation governing the European Union because the research will involve three case studies of geographically isolated areas within Europe and their current and possible future methods of paper waste management. The first and primary case study area is the Isle of Wight in southern England, the second are the Shetland Islands off the north coast of Scotland and the third area is Nordfjord, on the west coast of Norway. Although Norway is not a member of the EU, it has signed up to the European Economic Agreement and is thereby obliged to follow the European waste legislation, as are the other two areas.

All three of the case study countries are governed by the EU Directives (Table 2.1), but vary in how proactive or reactive they are to the Directives in their national waste management policies. This research will assess how the areas meet the same legislative targets.

EU waste legislation comprises three main elements:

- Horizontal legislation establishes the overall framework for the management of wastes (Waste Framework Directive).
- Legislation of treatment operations such as landfill and incineration sets technical standards for the operation of waste facilities (Integrated Pollution Prevention and Control, Landfill and Incineration Directives).
- Legislation on specific waste streams, such as oil, batteries, packaging. This includes measures to increase recycling or reduce the potential hazard of waste (i.e. Packaging and Packaging Waste Directive).

The original Waste Framework Directive of 1975 has been revised many times, and although it is the major waste directive, the so-called 'Daughter' Directives are the important Directives for day-to-day waste management (Incineration Directive, Packaging Directive, and Landfill Directive). These Daughter Directives set out the specific policies and practices that member states must implement in order to meet the general aims of the Framework Directive.

Directive	**Key point**
Waste Framework Directive (Dir 75/442/EEC)	• Recommends the use of the waste hierarchy, where the reduction of waste is given priority over the re-use of waste, over recycling, then incineration, then landfill as the last option. • Recommends the 'proximity principle' where waste is disposed of as close to source as possible. The latest revision of the Directive sets a recycling rate of 50% by 2020 (2008). • Ensures that waste is recovered or disposed of without endangering human health and without using processes which could harm the environment. • Prohibits the uncontrolled disposal of waste; ensures that waste management activities are permitted (unless specifically exempt). • Establishes an integrated and adequate network of disposal installations. • Requires the development of waste management plans. • Ensures that the cost of disposal is borne by the waste holder in accordance with the polluter pays principle.

	• Ensures that waste carriers are registered.
Directive on Integrated Pollution Prevention and Control (96/61/EC)	• Lays down measures to prevent or reduce emissions to air, water and land, including measures concerning waste. • Requires the avoidance of the production of waste and where waste is produced, it must be recovered or, where that is technically or economically impossible, it must be disposed of avoiding or reducing any impact on the environment. • Specifies that permit applications must identify measures for the prevention and recovery of waste generated by the installation. This covers waste management plants and paper mills.
Landfill Directive (99/31/EC)	• Requires a substantial reduction in the amount of biodegradable municipal waste (BMW) being land- filled: • by 2010 to reduce BMW landfilled to 75% (by weight) of that produced in 1995 • by 2013 to reduce BMW landfilled to 50% (by weight) of that produced in 1995 • by 2020 to reduce BMW landfilled to 35% (by weight) of that produced in 1995.
Incineration Waste Directive (2000/76/EC)	• Sets emission limits requiring the use of stringent operational conditions and technical requirements. • Sets requirements concerning normal and abnormal operating conditions, water discharges from cleaning exhaust gases, ash recycling, and plant control. Monitoring and public access to information.
Packaging and Packaging Waste Directive (94/62/EC)	• First Directive that includes specific recycling rates, where members are obliged to meet targets for the recovery and recycling of packaging waste: • By 2006 an overall recycling rate of 60% with minimum values ranging from 75% for glass to 20% for plastics. An 80% target was considered for 2008. • Places direct responsibility for meeting waste reduction targets on all manufacturers, importers and distributors of products in EU market.

Waste Shipment Regulation (2007) and (2011)	• Develops a strong framework for waste transport. • Bans the export of hazardous wastes from the EU to developing countries. Bans the export of waste from the EU for disposal in countries outside the EU. • Establishes greater enforcement measures and streamlines existing procedures.

Table 2.1. Key features of EU Directives affecting paper waste management.

The EU's legal framework provides the basis of waste management practices across the community, and the connections between the Directives and waste management is outlined in Figure 2.1 below.

The EU Waste Framework was revised in 2008 (European Commission 2008) to include a 50% recycling target for household waste such as paper, metal and glass and a 70% recycling rate for construction and demolition waste (letsrecycle.com 2008). The revision also calls for a reduction in the landfilling and incineration of waste due to pollution problems. However, the most efficient energy-from-waste incinerators will be classed as 'recovery' due to the energy recovered and will not be limited by the above restrictions.

The European Parliament has an aim of stabilising waste production by 2012, based on levels generated in 2008. There is a proposal that waste production should begin to decline from 2020. Within the revision is also a proposal that member nations should draft prevention programmes within 18 months of the revised Directive's entry into force. One amendment requires member states to establish separate collection systems for waste paper, plastics, metals, glass and textiles. The Parliament has introduced a new article requiring member states to ensure separate collection, treatment and safe use of bio-waste within three years of the Directive's adoption.

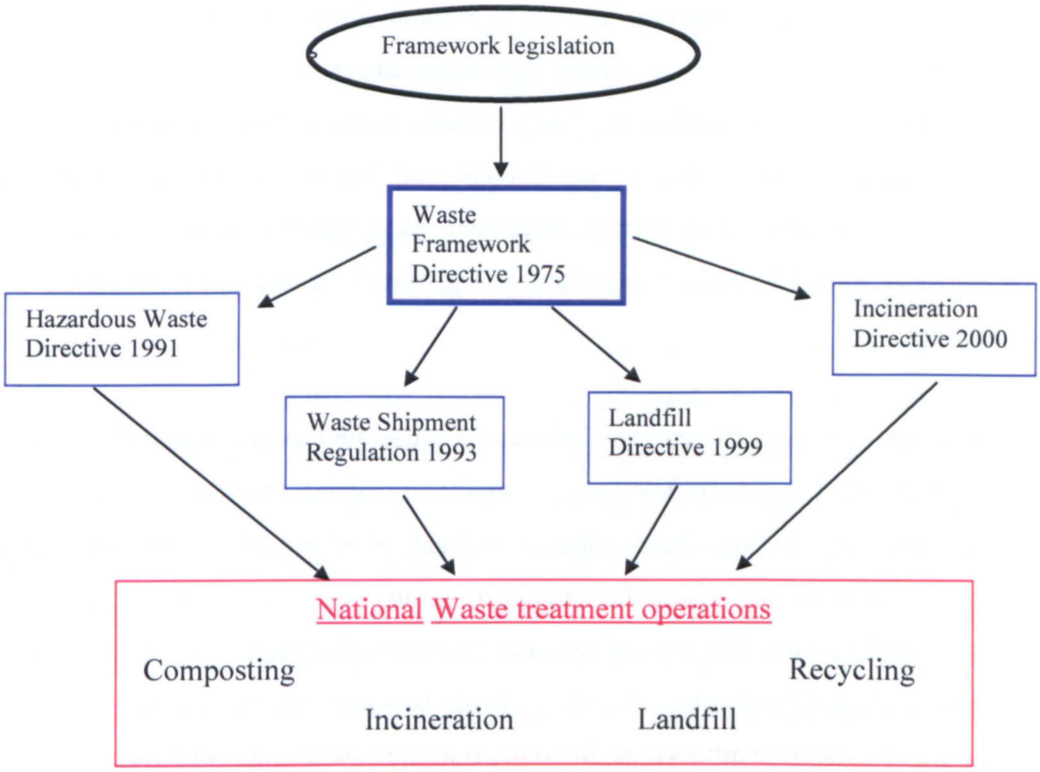

Figure 2.1. The interaction of EU Waste Directives (Source: Defra 2006a)

Waste policies have been developed at the European Union level mainly because pollution does not respect national boundaries and also because individual member states have allowed producers and businesses to adopt inadequate environmental standards, giving them an advantage within international trade (Defra 2006). The Directives aim to reduce the production of waste and its hazards to the environment and human health. They also aim to encourage the recovery of materials, preferably through re-use and recycling, and find the optimum final disposal method, with improved monitoring minimising waste's potential to cause damage to the environment and human health.

2.3 UK Waste Legislation

The UK legislation is divided into national legislation, such as the 1999 Pollution Prevention and Control Act (HMSO 1999), which covers the whole of the UK and regional legislation, such as the waste strategies, where England and the devolved administrations each has its own strategy (Defra 2007, Scottish Government 2010, Welsh Assembly Government 2010, Northern Ireland Department of the Environment 2006).

Current UK waste legislation can be said to originate from the Control of Pollution Act 1974 (HMSO 1974) which was further developed into the Environmental Protection Act (HMSO 1990). Legislation originally focused on the disposal of waste, but since the introduction of the EU Framework Directive on Waste (Section 2.2), control has been extended to include the storage, treatment, recycling and transport of waste. In recent years, most UK waste legislation has been implemented as a result of EU Directives.

The concept of 'Duty of Care' was introduced under the Environmental Protection Act (HMSO 1990). Any person who imports, produces, carries, treats or disposes of waste is subject to duty of care, whereby they must 'take all reasonable measures to prevent the escape of waste and ensure the transfer of waste only occurs to an authorised person' (Defra 2006). The duty of care also prevents other parties illegally treating, keeping or disposing of waste. The duty of care was amended in February 2003, to allow waste collection authorities, in addition to the Environment Agency, to check whether businesses were completing and retaining their transfer notes correctly. It was further amended in 2005 to include all householders being responsible for passing their waste on to a registered carrier.

The Pollution Prevention and Control Act (1999) transposed the Integrated Pollution Prevention and Control (IPPC) Directive into UK law. This new legislation stated that certain waste management facilities have to apply and receive a permit to operate. Incineration plants with a capacity exceeding 3 tonnes per hour, installations for the disposal of non-hazardous waste with a capacity exceeding 50 tonnes per day, landfill sites receiving more than 10 tonnes per day and paper and board facilities with a production capacity exceeding 20 tonnes per day are all covered as required by the IPPC Directive (European Commission 1996).

The requirements of the Landfill Directive are implemented through the Landfill (England and Wales) Regulations 2002 (HMSO 2002). In particular, the diversion of biological municipal waste (BMW) needed primary legislation and was implemented through the Waste and Emissions Trading Act (WET) 2003 (HMSO 2003).

Direct government intervention in pricing policies can help to achieve environmental goals by ensuring that prices reflect environmental impacts and discourage behaviour that damages the environment. The Landfill Allowance Trading Scheme (LATS) was introduced in April 2005, as the world's first trading scheme for municipal waste and as one of several policies introduced to improve waste management strategies from Local Authorities (Defra 2006). The trading scheme allowed opportunities to trade flexibly, bank or borrow landfill allowances, which enabled local authorities to meet the Landfill Directive targets in a cost-effective way. This means that local authorities are allocated a permitted tonnage of waste they can landfill, based on the biodegradable waste they sent to landfill in 2001/2. If the authority landfills less than the permitted amount, the excess can be sold to other authorities. On the other hand, if the authority needs to landfill more than their allocated amount, they are able to buy extra tonnage from an authority which has not used their allocated amount. The total number of allowances across the country is limited according to national targets set out in the European Landfill Directive. LATS includes financial penalties for local authorities who exceed their allowances for biodegradable municipal waste and this encourages the authorities to plan ahead and invest in infrastructure. LATS are a part of the change from previously relatively cheap landfill 'solutions' to alternative waste management options required by the Landfill Directive. The scheme was reviewed by the Environment Agency (2010) and the report concluded that the scheme was working well and England was ahead of its targets for meeting the EU targets for decreased biodegradable waste to landfill. However, the LATS scheme will be stopped in 2013, as Defra has decided that the Landfill Tax is the driving force behind the reduction of waste going to landfill and the LATS scheme is no longer necessary (Defra 2011).

The Producer Responsibility Obligations (Packaging Waste) Regulations 1997 transposed the Packaging and Packaging Waste Directive into UK law (HMSO 1997). These regulations obliged businesses with an annual turnover of £2 million and handling more than 50 tonnes of packaging a year to:

- Register with the Environment Agency or a compliance scheme,
- Recover a specified tonnage of packaging, according to whether they were retailers or packers,
- Certify that their obligations have been met,
- If retailers, to inform their consumers of how they are increasing the recycling and recovery of packaging materials.

The Packaging (Essential Requirements) Regulations (1998) (amended in 2003 and 2009) (HMSO 1998) specified obligations for packaging placed on the market, which included a minimisation of packaging weight and volume consistent with safety, hygiene and consumer acceptance. These regulations also require a design and use of packaging which allows re-use and recovery and limits the concentrations of lead, cadmium, mercury and chromium permitted in packaging materials.

The Household Waste Recycling Act (2003) stated that local authorities with the responsibility for collecting waste should separately collect at least two recyclable wastes by the end of 2010 (Defra 2005). Local authorities could only be exempt from the arrangements if 'the cost of complying was unreasonably high or where comparable alternative arrangements were available, or where the Secretary of State had made a direction that the duty should not apply to the waste collection authority until a later date (before 31.12.2015)'. The aim of the Act was to increase the rate of recycling of household waste which was 14.5% in 2003. The implementation of the Act was planned to assist local authorities to meet the targets set out in the Waste Strategy 2000; to recycle or compost at least 25% of household waste by 2005, 30% by 2010 and 33% by 2015.

The Waste Strategy for England 2007 aimed to reduce the production of waste and to break the link between economic growth and waste growth. The strategy stated that 'most products should be recycled. Energy should be recovered from other waste where possible' and that 'for a small amount of residual material, landfill will be necessary'. This strategy was reviewed in 2011, but made no changes to any of the strategy targets (Defra 2011b).

2.4 English and Welsh Waste Policies

The waste strategies for England and Wales (until 2007, joint strategies covered both England and Wales) were prepared to meet the measures for implementing the EU Directives (Table 2.2).

Title	Date	Status	Source	Key features
Making waste work	1995	Waste strategy	DoE	Set 25% recycling/composting target for 2000 and 40% recovery target for 2005, as a measure to implement the 1975 Waste Framework Directive.
Less Waste More Value	June 1998	Consultation paper	DETR	Published Environment Agency data on waste arisings. Asked for views on targets, hierarchies, etc.
A Way With Waste	June 1999	Draft Waste Strategy	DETR	Noted that Making Waste Work targets would not be achieved and proposed more stringent, but with a longer timescale.
Waste Strategy 2000	May 2000	Waste Strategy for England	DETR	Issued to meet Section 44a of Environmental Protection Act (EPA 1990), which implements Framework Directive requirement for a waste management plan. Separate strategies now exist for Wales, Scotland and Northern Ireland. Set national recycling and recovery targets for MSW. Re-iterated the importance of BPEO in waste planning.
Waste Not Want Not	Nov. 2002	Strategy Unit Report to Defra	Defra	Commented on the Waste Strategy 2000. Called on further Government action to tackle the waste problem. Suggested various new targets.
The Draft Waste Strategy	2006	Interim review of Waste Strategy2000	Defra	Reflected on existing policies and delivery mechanisms. Consultation on proposals for a revision of the National Waste Strategy for England. Sets out progress made since 2000 in meeting Government objectives. Consults on proposals to revise Waste Strategy 2000.
Waste Strategy 2007	May 2007	Waste Strategy for England.	Defra	Reviewed developments in waste management since Waste Strategy 2000. Targets include Household waste recycling: 2010- 40%; 2015 – 45%; 2020 – 50%. Municipal waste recovery: 2010 – 53%; 2015 – 67%; 2020 – 75% Commercial and industrial waste: 2010 – Expected 20% reduction from 2004 levels.
Towards Zero Waste	2010	Waste Strategy for Wales	Welsh Assembly	70% recycling by 2025 including businesses, households and the public sector. Zero waste by 2050.
Government Review of Waste Policy in England 2011	June 2011	Waste Strategy Review for England.	Defra	Use waste hierarchy and reduce carbon footprint of waste. Encourage waste reduction and re-use. Develop voluntary approaches to cutting waste. Consult on increased targets for packaging waste recycling. Support energy from waste and anaerobic digestion where recycling not possible. Support improved collection of waste from small businesses.

Table 2.2: Waste Strategies and related reports.

Best Value has been applied to local authorities since April 2000. Best value places a duty on local authorities to secure continuous improvements in the way they exercise their functions in regard to the combination of economy, efficiency and effectiveness (Defra 2006). Best Value Performance Indicators are used to measure the success of the local authorities in meeting Government targets in waste management. These indicators are:

- The percentage of household waste arisings being recycled by the waste authority,
- The percentage of household waste sent by the authority for composting or treatment by anaerobic digestion,
- The percentage of the total tonnage of household waste arisings which have been used to recover heat, power and other energy sources,
- The percentage of household waste arisings which are landfilled,
- The number of kilograms of household waste collected per head of population,
- The cost of household waste collection per household,
- The percentage of households in the area served by kerbside collections of recyclables,
- The percentage of households served by kerbside collections of two recyclables.

The Waste Strategy for England (2007) aimed to reduce the production of waste and to break the link between economic growth and waste growth. The strategy stated that "*most products should be recycled. Energy should be recovered from other waste where possible*" and that "*for a small amount of residual material, landfill will be necessary*".

2.5 Scottish waste policy

The first Scottish Waste Strategy was built up by eleven separate areas in Scotland finding the Best Practicable Environmental Option (BPEO) for waste management in their area. These results were then combined to produce the National Strategy (Scottish Executive 2003). This process is an example of a 'bottom-up' planning process, in contrast to the Waste Strategies for England and Wales which were produced for the Government and imposed on the separate regions, an example of a 'top-down' process.

In Scotland, BPEO has been applied within the waste strategy framework to try to balance social, economic and environmental costs and benefits. The Orkney and Shetland Area Waste Management Plan describes the BPEO for municipal solid waste (MSW) and sets out the process by which the BPEO will be determined and implemented for all other wastes. The process of assessing the Orkney and Shetland BPEO for MSW placed particular emphasis on proximity and self-sufficiency and the need to recover locally as much value as possible from waste to provide social and economic benefits. This same emphasis was to be applied in developing non-MSW BPEO(s) (SEPA 2003a).

The Environmental Protection Act (1990), as amended by the Environmental Act (1995), set out the powers and duties of the waste regulation authority in Scotland relating to waste management licenses. In accordance with the Waste Framework Directive (1975), any establishment which kept or disposed of waste had to obtain a permit to do so from SEPA. The Environment Act also gave SEPA the duty to prepare waste strategies for Scotland.

As the sum of the area strategies mentioned above, Scotland prepared a National Waste Plan (2003) which gave emphasis to the importance of reducing the quantity of MSW and encouraging composting and recycling through collection and 'bring' sites. This was hoped to reduce the scale of new facilities required to treat and dispose of mixed waste. Local authorities were encouraged to examine local waste solutions for each area and to work cooperatively with neighbouring areas.

In 2003 Scotland produced over 3.3 million tonnes of municipal waste each year of which over 2.6 million tonnes were collected from households (Scottish Executive 2003). Two interim targets for managing this waste were:

- To increase the amount of waste collected by local authorities for recycling or composting to 25% by 2006;

- To reduce the landfilling of bio-degradable waste collected by local authorities to 1.5 million tonnes per year by 2006.

Audit Scotland (2007) produced a report that suggested that the rate of recycling would have to increase and the amount of waste going to landfill be reduced to meet the EU Directive targets. The key findings of the report were:

- A need for a reduction in biodegradable waste sent to landfill despite the increased waste generated from households.

- Expenditure by Scottish local authorities on recycling would have to increase from £351m in 2005/6 to £580m in 2007 to attain EU Landfill Directive targets.

- A need for inter-agency cooperation for more effective progress in waste minimisation, recycling and waste treatment. Councils, SEPA (Scottish Environment Protection Agency) and the Scottish Government needed to consider how they could work with the waste industry to deliver the waste treatment facilities to achieve the targets.

In 2008, the Environment Secretary proposed a consultation period on new recycling targets:

- The amount of MSW to be recycled to be increased to 60% by 2020 and 70% by 2025,

- The landfill of MSW to be reduced to 5% by 2025,

- No more than 25% of MSW to be used for energy recovery by 2025 and large inefficient incinerators to be modified to increase efficiency,

- To keep the existing target of stopping the growth in MSW by 2010 (SEPA 2009).

These targets now form part of Scotland's plan for "zero waste" (Scottish Government 2010). This document sets out measures to develop waste prevention plans for all types of waste, a 70% target for recycling and a maximum of 5% sent to landfill by 2025, restrictions to the input of waste incinerators to promote re-use and recycling and a ban on the landfilling of unsorted waste and biodegradable waste by the end of the decade.

2.6 Norwegian waste legislation

Norway is not a member of the European Union, but has signed up to the European Economic Agreement (EEA), which binds the country to all of the Waste Directives.

The Norwegian Law for the Prevention of Pollution and Waste (Lov om vern mot forurensninger og om avfall) (Norwegian Government 2006) was last amended in May 2006. It includes the Polluter Pays Principle for any unlawful waste activity, which means that those who produce waste or emissions are responsible for the cost of limiting the environmental damage, or cleaning up the waste or emissions. The law also states that local authorities are responsible for the collection and management of municipal waste. Industrial and commercial waste is the responsibility of the producer. The local authority decides whether waste should be re-used, recycled, incinerated-for-energy or landfilled, on the basis that the environmental benefits are reasonable in relation to the costs. The local authority is also responsible for deciding gate prices to cover the costs of collection, transport, acceptance, storage and management of the waste, a so-called 'green tax'.

The following aims and objectives were included:

- The damage to people and the environment caused by waste to be minimised. To achieve this, waste problems were to be solved by means of policy instruments that ensured a good socio-economic balance between the quantity of waste generated and the quantities recovered, incinerated and landfilled.
- The growth in the quantity of waste generated to be considerably lower than the rate of economic growth, due to increased recovery and recycling of waste.
- A ban on the landfilling of all biodegradable wastes, including paper.
- The proportion of waste recovered to be raised to approximately 75 per cent of total waste in 2010 and subsequently to 80 per cent. This was based on the principle that the quantity of waste recovered should be increased to a level that was appropriate in economic and environmental terms.
- Practically all hazardous waste to be dealt with in an appropriate way, so that it was either recycled or sufficient treatment capacity be provided within Norway.
- Obligatory waste and environmental management plans.

The Government had the following waste strategy targets:

- To take steps to raise the proportion of waste recovered, with the aim of reaching 80%.
- To implement a strategy for biodegradable waste, which included the introduction of waste management plans as a mandatory element of all building projects and the prohibition of landfilling of biodegradable waste, planned to take effect from 1 January 2009.
- To implement a new strategy to increase the proportion of hazardous waste delivered to approved facilities.
- To play an active role in the development of new legally binding and globally applicable rules to ensure that ship recycling was carried out in an environmentally sound way.
- To allow local authorities to choose specific solutions for the collection and treatment of waste, whilst continuing with the central authority frameworks.
- To increase the utilisation of the energy potential in waste whilst reducing polluting emissions from the incineration process.

Norway's waste production increased by 17% between 1995 and 2005 (Statistisk sentralbyrå 2010). In this ten year period MSW increased by 55%. However, due to an increase in the recycling and recovery of waste, the amount being sent to landfill sites decreased by 3%. Whereas ten years ago 45% of all waste was landfilled, it was 25% in 2006, with an increase in recycling from 31% to 43% in the same period. The amount of paper in waste had increased by 33%.

Approximately 17% of all household and industrial waste was paper. Of this, 25% was recycled in 1990 and 51% in 1997. 90% of all brown paper was collected and recycled, mainly for the production of cardboard.

2.7 Waste management in isolated communities

The literature review identified some research on waste management and isolated communities. This examined the complete waste streams, certain parts of a waste stream or certain waste management options. However, no research was found that focused on one particular component (such as paper), comparing and contrasting several waste treatment options and with the combined inclusion of economic, environmental, social and legislative factors in isolated communities.

Research into the total waste stream by Skordilis (2004) studied the island of Corfu and the possibility of integrated solid waste management in a popular tourist area. The author maintained that waste products could be seen both as a potential source of pollution and as a secondary source of raw materials. The selection of a waste management system on Corfu concerned environmental, technical, economic and social policies. To incorporate all of these factors, Skordilis developed his own model, based on multi-criteria analysis which he called Worth Benefit Utility Analysis (WBU) used in conjunction with LCA and evaluating alternative solutions for the disposal of waste based on prioritised criteria from the various stakeholders. These criteria included the implementation of environmental policy, reduced ecological impacts, economic development and the implementation of improved technology. The waste treatment and disposal alternatives considered were:

1. Sorting at source, a material recycling centre, a composting plant and sanitary landfill,
2. Sorting at source, a material recycling centre, thermal treatment including energy recovery and sanitary landfill.

Skordilis concluded that the most efficient method for waste disposal in Corfu was a combination of material sorting at the waste source and the production of compost from the organic fraction. This was due to the evaluation by stakeholders giving priority to environmental benefits, reduced economic cost and reduced air pollution, which the above methods were assumed to provide (Table 2.3).

Treatment Options	Social acceptance	Unemployment	Air pollution	Water pollution	Land pollution	Reduced cost	Increased revenue	Better system	Longer life span
1	6	9	6	5	4	8	6	7	6
2	5	9	2	7	3	2	7	8	6

Table 2.3. Results of the research by Skordilis (2003). The scores given are a multiplication of ranking scores for each alternative and weighting scores given to each factor. Higher scores give the preferred option

The author maintained that the model and the decision-making process were more comprehensible to the local residents, due to the use of MCA and LCA. Social parameters were integrated into the financial, environmental and technological analysis and environmental policy was also included. The disadvantage of both the model and the analysis was the subjectivity of the people who evaluated the parameters, although the author suggested that the choice of stakeholders with different priorities and the use of sensitivity analysis minimised this disadvantage.

Research on the financial cost of waste management in isolated communities is also limited. On Green Island in Taiwan, Chen et al. (2005) analysed the cost-effectiveness and optimal timing of alternative solid waste management systems on small islands. The study examined three alternative scenarios using cost-effectiveness analysis;

- Option 1 – continue with the present scenario, where nearly all waste is landfilled, with transport of all waste to the mainland when the site is full in 2012,
- Option 2 – transport recyclables to mainland (up to 25%) and landfill the rest,
- Option 3 – transport recyclables to the mainland (up to 25%), incinerate the combustible fraction and landfill the rest.

The study concluded that the most cost-effective option was to promote recycling, whilst building an electricity-generating incineration plant and disposing of the ash in a sanitary landfill site. In addition, their study results showed that the most cost-effective option was to delay the building and operation of the incineration plant until 2010 to allow time to finance the construction of the plant (Figure 2.2).

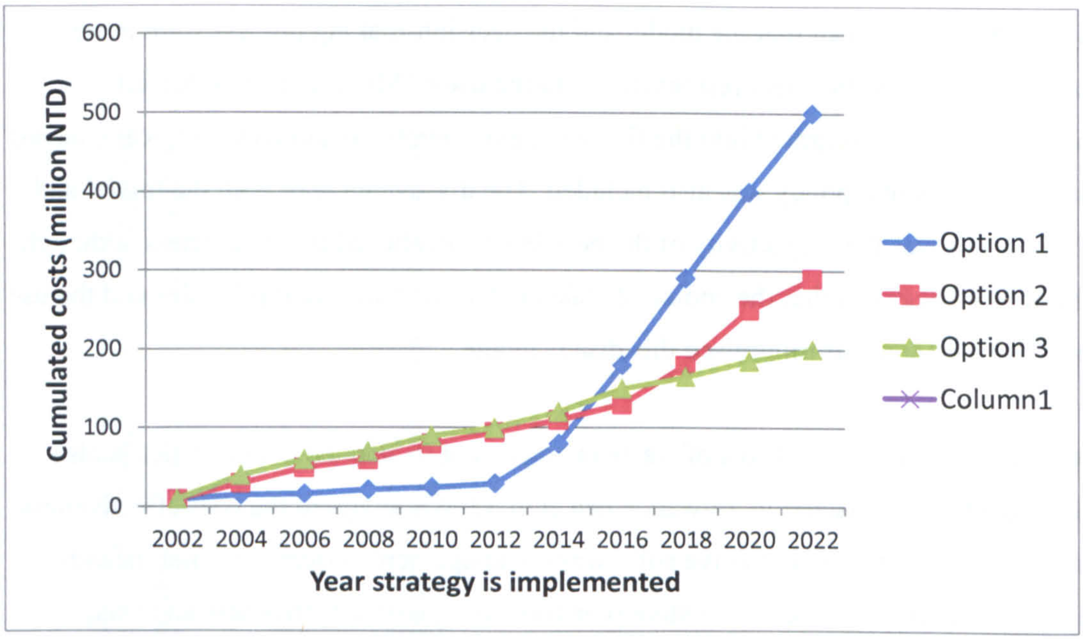

Figure 2.2. Results of cost-benefit analysis on Green Island. Source: Chen et al. 2005. NTD = New Taiwan Dollar. 100NTD = €2.70.

Due to the focus on the timing of investments for alternative SWM methods, the study was restricted to determining the direct costs of the methods. Indirect costs, such as the externalities (environmental impacts) of landfilling and incineration are not included. This means that, although the research found the best financial option, the effects on the island residents and the environment were not included in the study. The research did not consider recycling on the island as an option, due to its small geographical size and small population.

Other research has studied various parts of the waste management system. Purdy and Sabugal (2003) studied waste management on the island of Mindanao in the Philippines, where waste was disposed of in landfill sites. All of the facilities studied were open dumpsites spread throughout the island. An open dump is an area of land where all wastes are dumped, hazardous and non-hazardous, with little or no control of pollutants. The waste is often burnt to reduce the volume, producing air pollutants which could be detrimental both to human and environmental health. Open dumps also produce a lot of litter, noxious odours and disease carrying animals such as rats and flies. Human scavenging of such sites also has adverse health effects on those people involved. The investigation involved looking at alternative disposal sites, improving collection methods and placing waste in sanitary landfills, with liner systems and daily cover. Mindanao is an example of poor waste management methods in a financially poor area, where the result is greater impacts on the island environment (ground water contamination, insect and rodent infestations) and the communities that live nearby, who suffer from disease and odours spreading from the sites. The authors stated that the municipalities wished to operate sanitised landfill sites, but had neither the finances nor the technical expertise to make changes. The Philippine Government passed a law (the Ecological Waste Management Act 2003), which allowed no new open dumps and phased out their operation altogether within five years. Tacurong, a municipality on Mindanao, developed a ten year solid waste management plan that included recycling, composting and the separation of waste, as well as the conversion of its open dumps to a controlled site and eventually to a sanitary landfill site. Bais City landfill had a liner made of local clay which was planned to be used at other landfill sites.

In contrast, Bai and Sutanto (2001) studied waste management on the island of Singapore. Over the previous two or three decades, rapid industrialisation and economic development were found to have caused a tremendous increase in solid waste generation. The hierarchy of waste management in Singapore was waste minimisation (reduce, re-use, recycle), followed by incineration and landfill. Due to the very limited space available for landfill sites and the need to conserve capacity for the future, the development of incineration plants was given top priority over all other disposal methods. A programme for domestic solid waste separation was planned and implemented in 2001 to promote material recycling. At the Asia 3R Conference in November 2006, the National Environment Agency and the Ministry of the Environment and Water Resources in Singapore described the recent development of four incineration plants, which disposed of 90% of Singapore's waste, with the rest going to landfill (Anon 2006). However, the rate of increase in waste was unsustainable and the next decade will include increased recycling and a reduction in waste production, to reduce costs and the effects on the environment.

Miranda et al. (2004) used social cost analysis to study the suitability of Waste to Energy (WtE) technologies on the island of Puerto Rico. Social cost analysis examines the economic, environmental, human health and social costs of a waste management option. In this study the authors analysed the suitability of WtE technologies from both an energy production and waste management perspective. Using data and technologies from Germany, Sweden and the UK the study found that WtE plants may represent a reasonable alternative when:

- Fossil fuel production and its external costs are high (external costs being defined as 'the depletion of finite resources or the environmental damage that might be caused (Burnley et al 2003))
- Landfill production and its external costs are high
- WtE production and its external costs are low
- WtE production processes are able to maximise energy efficiency.

The authors maintained that many of these conditions apply to island communities like Puerto Rico, with a high dependence on imported fuel, difficulty in finding areas for larger, low-cost landfill sites, with vulnerable natural environments and areas of high population density. On Puerto Rico WtE technologies were seen to represent a reasonable energy source, whilst providing a method to dispose of waste. The limited availability of sites for landfill was an issue, as well as the cost of building small recycling plants in relation to the amount of waste being disposed of. The authors stated that the recovery and re-use of by-products of the WtE process could enhance the cost-effectiveness of WtE technologies. However, isolated communities have variable markets for and expected income from the sale of recovered or recycled goods. These markets, and the prices involved, would have an impact on the appropriate solid waste management choices. The authors were not able to obtain up-to-date information on the composition of waste being produced and were therefore unable to assess the efficiency of the proposed waste to energy facilities. This means that their conclusions were based on extrapolated data from European countries, which could increase the margins of error and affect the conclusions reached by the study. The authors were aware of the problems of giving economic values to externalities such as human health and environmental damage and, in addition, were using figures from areas outside of Puerto Rico, with a temperate climate. As they state, the level of impact of a pollutant is variable, depending on the environmental and climatological conditions, time and period of exposure and the behaviour of the local human population.

Other research has studied the possible use of ash from incineration plants as construction material and the incineration of waste with energy production in the form of hot steam (Miranda and Hale 1997, Hassan et al. 1999, Mendes et al. 2004). These studies concluded that the above methods of waste disposal either did not increase the environmental benefits above those of electricity-generating incineration or were not economically or commercially viable for isolated areas.

Currently, many island communities incinerate waste, including paper, to produce energy (Island Waste (2010), local websites, Skordilis (2003), Chen et al. (2005), Purdy and Sabugal (2003), Bai and Sutanto (2001), Miranda et al. (2005), Mendes et al. (2004)) (Table 2.4). The use of incineration reduces the amount of waste going to landfill, reduces the need to transport waste and recyclables across geographical barriers and reduces the need for imported energy. However, there are still many communities that export waste to the mainland for processing there.

The definition of isolated communities in this thesis (Section 1.2) states that such areas are separated from other conurbations by geographical barriers. To identify the BPEO for paper waste management in isolated communities it is important to consider the particular geographical boundaries that have to be crossed to reach other areas, the time-scale and economics of any suggested option, as well as the environmental and social impacts of each option.

Geographically isolated areas generally have a limited ability to dispose of waste in landfill sites, as well as legislation which requires the reduction of waste sent to landfill. The other options are to transport waste away to disposal or recovery sites in other areas, or to develop alternative strategies within the area. Many island communities are also popular tourist destinations, both adding to the amount of waste generated and the need to find sustainable disposal methods which preserve the environment and the tourist trade within the area.

In conclusion, the literature review on isolated communities has found that there is no research which covers the comparison of landfill, recycling, incineration or other treatment methods for paper waste in terms of financial, environmental, legislative and social factors. In addition, there is no research which uses three different isolated communities as case studies, comparing and contrasting the areas with each other to find the best waste management option for each of them.

Island	Area (km^2)	Population	Population density (per km^2)	Distance from mainland (km)	Waste Production (1000 t/yr)	Incinerator?	Heat output	Power output	MSW burnt (%)
Corfu	641	110 000	172	3	60	No	-	-	-
Crete	8 336	650 000	77	160	260	No	-	-	-
Cyprus	9 251	861 000	93	64	474	No	-	-	-
Gibraltar	5.8	29 000	5 000	1.6		No	-	-	-
Gotland	3 000	57 000	19	97	40	Yes	No data	No data	12.5
Green island	15	3289	219	33	4281	No	-	-	-
Guadeloupe	1 780	344 000	193	6920	258	Yes	-	74MW	38
Guernsey	78	65,573	836	48	45	No	-	-	-
Isle of Man	572	80 000	139	83		Yes		6MW	80
Isle of Wight	300	126 000	420	5.6	87	Yes		2.2MW	48
Majorca	3 639	736 865	202			Yes		90MW	16
Mindanao*	94 630	21.5 million	168			No	-	-	-
Puerto Rico	8 000	3.84 million	480		4 120	No	-	-	-
Orkney	523	19 900	20	11					
Sardinia	23 812	1 657 000	70	193		Yes		12MW	6
Shetland	1 468	17 550	12	160	11.6	Yes		7MW	26 000
Sicily	25 711	5 172 000	196	3.2					
Singapore	697	4.2 million	5 894		2800	Yes (4)		140MW	73
Taiwan*	35 600	23 million	609	180	5 600 000	Yes (19)	No data	No data	

Table 2.4. Geographically isolated communities and solid waste incineration. Source: Island Waste (2010), local websites, Skordilis (2003), Chen et al. (2005), Purdy and Sabugal (2003), Bai and Sutanto (2001), Miranda et al. (2005), Mendes et al. (2004). * Mindanao and Taiwan are included as examples of geographically isolated areas with large populations.

2.8 Financial models

This section considers the financial models used in previous research into paper waste management, the types of models used and the gaps in the literature which will be covered by this research.

The literature research into economic data has revealed a lack of consistent data for paper waste management. Table 2.5 summarises the data available for paper and card waste.

Author	Date	Subject
Berglund and Søderholm	2003	Utilisation of recovered paper.
Berglund	2004	Spatial cost efficiency in waste paper handling.
Brisson	1993	A market-based instrument (a packaging charge) would offer a more cost-effective solution to the problem of packaging waste and litter than regulatory legislation.
British Newspaper Manufacturers Association	1995	Incineration vs. Recycling.
Byström and Lönnstedt	1997	Environmental and economic impact of paper recycling.
Craighill and Powell	1996	LCA and economic evaluation of paper recycling.
Dahlbo et al.	2005	Management of waste newspapers.
Hanley and Slark	1994	The financial viability of paper recycling.
Hummel	2002	Waste collection costs.
Ingham	1999	Recycling markets.
Murphy and Power	2006	Technical, environmental and economic analysis of energy production from recycled newspaper.
Pati et al.	2006	Management of paper recycling system.
Petersen and Andersen	2002	Waste paper incineration.
WRAP	2011	Report on gate fees.

Table 2.5. Summary of the financial literature.

As Table 2.5 shows, there are a number of research papers into the economics of paper waste management, looking at the financial costs of different options and different types of waste paper. However, the research is concentrated on recycling, incineration and landfill without considering other disposal methods, such as composting and gasification. There is also research into components of the waste management system, such as collection costs or recycling. The literature review could find no research which looked holistically at the complete paper waste stream and isolated communities, the specific financial problems such areas have in paper waste disposal and then the incorporation of these into further research into the environmental and social effects of the waste management options.

In the literature review there were three articles found which used macro-economic models when studying paper waste management. All three examined waste paper markets. Brisson (1993) used macro-economics to examine methods of reducing packaging waste in various countries across the world and concluded that the best method of reducing waste was to introduce a packaging charge, reflecting the costs of disposal, but also taking into account the recycling rates of the material involved. The author of the paper maintained that this charge would be more effective at reducing waste than regulatory targets. The charge was also meant to internalise the environmental costs.

Again, using macro-economics, Berglund and Söderholm (2003) argued that paper recovery and recycling rates within a particular country were governed by the availability of waste paper and virgin fibre as well as the economic level of the country. They maintained that the setting of recycling and recovery rates should reflect these factors. If, for example, a country like Canada, with a rich supply of virgin fibre and a net export of paper products was to increase recovery rates it would mean the import of waste paper from other countries, which might be neither economically or environmentally viable. Thus recovery rates in different countries and also possibly within countries (due to population densities) should not be standard but flexible.

Ingham (1999) focused on 'classic' industrial market failures such as a lack of information, technological externalities, market power, transaction costs, etc. Ingham argued that environmental policies had been introduced within waste management without considering the functioning of the economic market.

Cost benefit analysis (CBA, See Glossary) was used by Hanley and Slark (1994) and Berglund (2003) to research the recycling of paper from an economic and environmental standpoint. Their conclusions agreed the need for political intervention to maintain optimum recycling rates, due to large fluctuations in prices for recycled paper. Hanley and Slark did not consider the methodological strengths and weaknesses of CBA as a tool, nor did they claim that CBA was the best tool for making environmental decisions. However, they maintained that the tool was still useful as a systematic method of investigating the recycling of paper in Scotland. The study concluded that recycling was preferable to landfill if external costs, such as emissions, are included. The financial costs alone did not give this preference. Neither did the CBA give a clear preference for recycling above incineration, recycling only being preferable when waste paper prices were high.

Berglund examined the assumptions behind the political acceptance of recycling over the incineration of paper. He argued that there had been little analysis of the economics of recycling and whether it was a policy that was beneficial to society as a whole. In his terms 'beneficial' was measured using the Hicks-Kaldor Criterion which states that 'economic efficiency implies that the sum of the benefits is great enough to offset the costs' (Berglund 2004). Swedish society at the time had no incinerators and all recovered paper was recycled. He argued that Swedish recycling policies and the government legislation that required all areas to recycle 65% of paper and cardboard was not always beneficial and that this rate should be flexible to allow for reduced recycling in rural areas and increased incineration in areas remote from paper mills, where the costs and environmental damage from transport are high.

Although the author was studying the complete waste stream rather than just paper waste, Pickin (2008) criticised the use of CBA as a tool, due to the fact that the use of externality measurements and valuations had decreased the efficacy of CBA rather than giving the promised transparency and assistance it was hoped it would bring to waste management. He reviewed 37 different CBA studies within waste management and concluded that there were five crucial areas where the studies were inconsistent;

- The types of environmental impact and their valuation,

- The inclusion, or not, of 'up-stream' externalities, which increase the benefits of substituting for virgin materials and fossil fuels,
- The economic significance of householder activities,
- The scarcity of environmental resources,
- The measurement of the sustainability of a treatment system.

Pickin (2008) maintained that these inconsistencies and the problems surrounding the economic valuation of externalities allowed too much subjectivity into the analyses and, therefore, results reflected the interests of the commissioning institutions (institutional capture). The two studies discussed above do not allow any such conclusions, but the difficulties involved in CBA must be taken into account when the tool is used on its own.

2.9 Life cycle assessment and paper waste management

2.9.1 LCA methods

Life Cycle Assessment (LCA) has been defined by the Society of Environmental Toxicology and Chemistry as '*an objective process to evaluate the environmental burdens associated with a product, process or activity, by identifying and quantifying energy and materials used and waste released to the environment, and to evaluate and implement opportunities to effect environmental improvements*' (SETAC 1993). Thus this technique examines the inputs and outputs of energy and resources in the system being examined, covering 'cradle to grave' impacts from the production or start of a product or process to the end of its use or lifetime.

Udo de Haes et al. (1994) reviewed the development of the concept of LCA during the 1960s. The emergence of Life Cycle Assessment started with the undertaking of studies that aimed to optimise energy consumption, which were later developed into studies that took into account the consumption of raw materials. Eventually, the studies included not only the inputs of a system, but also the outputs, or emissions. The first complete life cycle analysis study, taking into account all the environmental impacts, from the raw material extraction to the disposal of waste, was undertaken for Coca-Cola in 1969 (Ecobilan undated). The aims of the study were to assess the use of glass or plastic for the product bottling, to choose between internal or external bottle production and to assess the end of life options (recycling or disposal) for the chosen bottle. Contrary to expectations, the study concluded that plastic was the better choice for bottle production. A number of sources refer to this study and its conclusions (for example Ecobilan (undated)), but an extensive search of the literature failed to find a traceable technical or academic report of the study.

The energy crisis of the 1970s led authorities to focus on energy use and conservation, with LCA being developed to compare different energy supply systems (Curran 1992). The scope of LCA was further developed over the next two decades, incorporating other environmental concerns such as global warming, ozone depletion, biodiversity and human health. During the 1980s LCA studies were carried out in a number of European countries and North America, but the studies used different methods and frameworks. Since then the aim has been to develop a common framework for all LCA studies, with a 'commonly accepted best practice documented in the international standards' (Department of the Environment 1997).

The European Environment Agency stated that an '*ideal LCA should include all stages in the product life cycle from the gathering of raw materials for production through to the point where all waste materials and emissions are returned to the earth, air or water*' (EEA 2006). Therefore, LCA will express the total environmental impact of a given system or product (Figure 3.3).

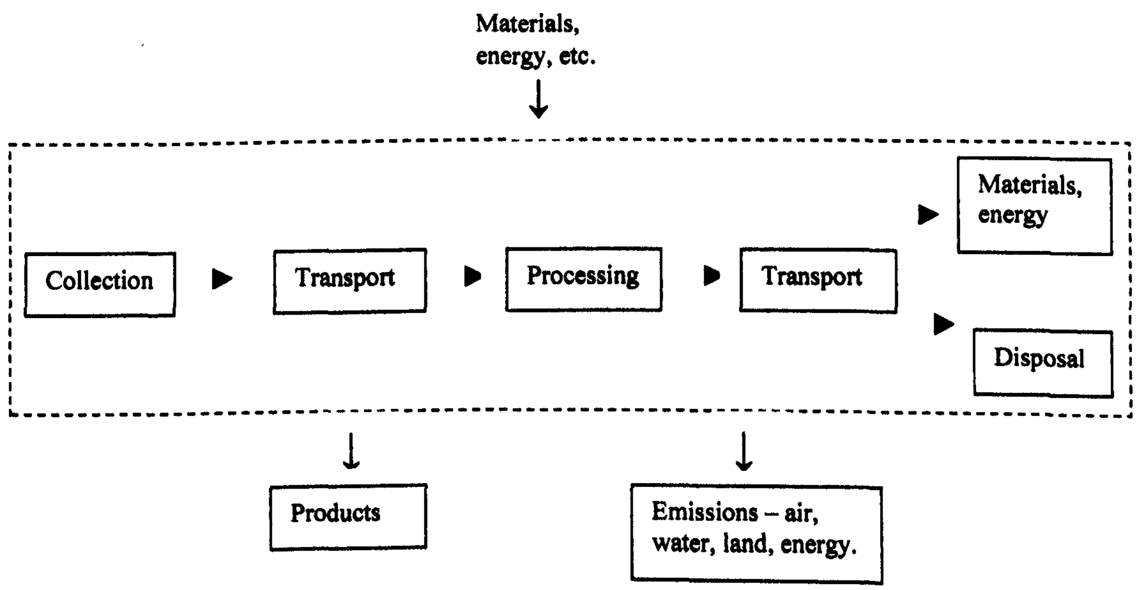

Figure 2.3: Schematic diagram of a life cycle assessment model.

The application of LCA can also lead to the identification of avoided burdens in a waste management system. For example, electricity generated from waste incineration processes displaces electricity from existing power stations, avoiding the associated environmental burdens.

The International Organisation for Standardisation (ISO) has standardised this framework within the ISO 14040 series on LCA (British Standards Institution 2006). The Life-Cycle Assessment framework as laid down is shown in Figure 2.4 below.

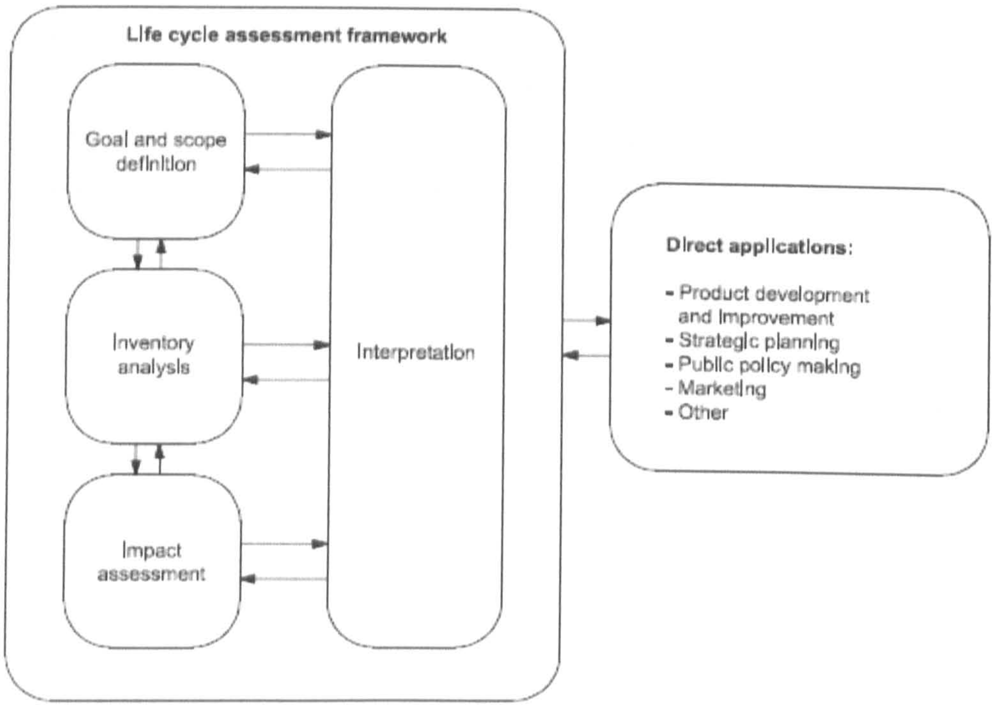

Figure 2.4. Life cycle framework (Source: British Standards Institution 2006).

There are many factors that need to be taken into account when carrying out LCA, all of which can influence the outcome of the study; for example, the amount of available information, the goal and scope of the study, the definition of the system boundary, the environmental impact factors chosen or the economic values chosen all affect the conclusions of the study. Thus the conclusions of an LCA will be affected by assumptions and choices made. However, a review of nine LCA studies carried out by the European Environment Agency in different geographical areas, all indicated that recycling resulted in fewer overall environmental impacts than both landfilling and incineration and the geographical differences between the areas were not large enough to affect these findings (EEA 2006).

To be able to make sustainable use of LCA in waste management decision-making, it is important to remember that the environmental information it produces is neither complete nor absolutely objective or accurate (Ekvall et al 2007). The international standardisation has helped to reduce the lack of consistency between studies, but important choices still remain to be made in each separate study:

- choice of time perspective (Finnveden et al 2005; Obersteiner et al 2007),
- assumptions made in the study,
- sources of input data,
- allocation of environmental burdens to different life cycles (Ekvall and Tillman 1997; Winkler 2007)
- modelling of environmental impacts.

2.9.2 LCA Tools

There have been a number of LCA tools developed over the years, but this section will focus on the UK's waste management LCA system (WRATE) and on one of the leading general-purpose LCA tool (SimaPro).

In the UK, the Environment Agency developed WISARD in 1994, which then evolved into WRATE in 2005 (See glossary). The WISARD LCA tool utilised a range of data, much of which was collected under the Agency's waste research programme. WISARD was officially launched in December 1999. It was designed so local authorities could use the LCA approach to aid in the development of such activities as waste management strategies. This was achieved by considering the environmental effects of different options for managing MSW, such as an integrated approach and understanding where the main environmental effects of the chosen waste management systems arise. The tool enabled the user to model existing and theoretical waste management systems for operations such as landfill, recycling, composting and energy from waste. WRATE combined these approaches with a new data base, covering a wider range of waste treatment technologies.

SimaPro is a widely used LCA software developed by PRé Consultants. The software allows users to model products and systems throughout their life cycles. It has a number of applications, such as product design, the calculation of carbon footprints of systems and products and the determining of environmental impacts. The software can analyse waste treatment systems, but is not built specifically for waste management users. Therefore it does not have the range of alternatives available on WRATE, where, for example, the choice is available for collection vehicle types, transport vehicle types, different recycling plants and energy from waste treatment plants.

One major advantage of using LCA on solid waste management systems is that the approach systematically covers all associated impacts within all processes, upstream and downstream of the waste management system. Another advantage is that the analysis aggregates over time, i.e. all inputs and emissions over the whole life cycle are included, regardless of when they occur. This holistic approach allows the evaluation of different waste technologies with different patterns of energy consumption or production and different levels of material recovery (Kirkeby et al. 2005).

As mentioned above, LCA is a standardised tool, with the purpose of minimizing potential impact on the environment, human health and on resources. The analysis has the potential to be universally acceptable as a measure of waste management performance, amongst industry, regulators and the public (Barton et al. 1996).

One main disadvantage of using LCA for waste management purposes is the fact that the stage of impact assessment and the increased use of computer modelling at this stage are all relatively new techniques (Burnley and Crompton 2003). This means that studies differ in depth, size and detail and results must be interpreted with this in mind. In addition, due to the aggregation over time of inputs and emissions, the analysis is not able to assess the actual environmental effects of the emissions and waste at one particular time in the life cycle (McDougall et al.2001).

There is also the problem of data gaps when using LCA as a basis for decision-making. Arngrimsson et al. (1999) found that there was a lack of data on the human end eco-toxicological impacts of waste management systems, due to the large number of possible pollutants that end up in waste or are produced by waste treatment methods. In LCA studies of future waste management options in three municipalities in Sweden, eco-toxicological impacts were not quantified due to a lack of data. More emphasis was therefore put on the total energy use and emission of greenhouse gases in the study, as these impact categories had better data availability. In the last decade, however, the effects of emissions on human health have been more fully incorporated in to LCA studies.

Traditional LCA includes the emissions and fuel demands of transport. It takes transport distances into account. However it does not differentiate between emissions occurring at different locations. Instead, all emissions of each specific pollutant are summarised without taking into account the geography and other factors of the localities (Ekvall et al 2007). The environmental impacts of several pollutants may depend heavily on where and when they are emitted. As an example, the sensitivity for SO_2 emissions was found to be more than a thousand times higher in Sweden than in Greece depending on how the impact was defined (Hauschild and Potting, 2004). When geographical information is not included, the impacts of these emissions may not be accurately described.

Pollution involves a large number of different chemical substances. Human society deals with thousands of chemicals, many of them with largely unknown characteristics. Since these chemicals are used in different products, a very large number of chemicals will end up in the waste management system. The fate of these chemicals in different treatment processes is difficult to model and include in an LCA. Furthermore, an LCA typically amalgamates substances of the same type into sum parameters such as polyaromatic hydrocarbons (PAH), volatile organic compounds (VOC), and total organic compounds (TOC) (Ekvall et al 2007). This is for practical reasons, since emissions are often reported in this manner in environmental monitoring. However, the environmental impacts may vary greatly between different substances within these parameters. Therefore, such measures reduce the ability of LCA to model accurately the environmental impacts. To minimize these disadvantages, it is possible to gain knowledge of a particular area or site and any possible impacts using an environmental impact assessment (EIA) or risk assessment. To increase the accuracy of the description of environmental impacts, some guidelines on LCA recommend that some parameters should be avoided and that data on emissions of specific substances should be used whenever possible. However, because of the number of chemicals used in society, there will always be data gaps for many chemicals that are relevant in environmental assessments.

2.9.3 The application of LCA to waste paper

This review identified a number of studies which used LCA for paper waste management research (Table 2.6). A number of conclusions can be drawn from this work.

The earlier studies, which were limited in their input of data, were generally supportive of recycling as the best paper waste management option. The later articles have varying conclusions about the advantages and disadvantages of recycling and incineration. The accepted idea is now that a combination of treatment methods is probably necessary to give an optimal management of waste paper.

Author	**Date**	**Subject**
Axel Springer Verlag	1998	The production of newspaper and magazines
British Newsprint Manufacturers Association	1995	Recycling vs. incineration
Byström and Lönnstedt	1997	Paper recycling
Craighill and Powell	1996	Recycling vs. landfill
Dahlbo et al.	2005	Newspaper life cycle and 5 alternative waste management methods
Grant et al.	2001	Recycling vs. landfill of paper waste
Kärnä et al.	1994	Recycling versus incineration
Leach et al.	1997	Waste paper management systems and LCA
Merrild et al.	2008	Recycling vs. incineration of paper waste
Petersen and Andersen	2002	Incineration of waste paper

Table 2.6. A summary of LCA studies in paper waste management.

One of the early articles by Craighill and Powell (1996) compared recycling to landfill and found that recycling was both preferable when measuring environmental impacts and when converting these impacts to economic values. However, the authors admitted to shortfalls in data, both within the recycling system itself and regarding the social and environmental impacts of the two management alternatives. The environmental and social impacts that were included were difficult to translate into monetary values. The authors admitted a need to use sensitivity analysis to analyse changes in the data used.

The British Newsprint Manufacturers Association (BNMA) (1995) found recycling to be more beneficial than incineration. The authors measured the environmental impacts of incineration and recycling and with the (then) best available technology (BAT) concluded that recycling was the better environmental option. Today's incineration technology and stringent emission controls mean that this is not necessarily the case now. The BNMA examination used CBA to give a financial value to the externalities and also included a discussion of the disadvantages of this method, but only measured three emissions. There was no analysis to measure the significance of other variables that might affect the outcome of the study, no discounting of financial values for future calculations of emission-effects and no discussion of geographical factors or the effects of time on their analysis.

Leach et al. (1997) came to the opposite conclusion. Using LCA in combination with Systems Analysis the results recommended incineration above recycling. Their study was also limited, examining six externalities, which emphasised the damage caused by CO_2 and greenhouse gases. When the emphasis is on greenhouse gas emissions, incineration becomes the better environmental option due to the recovery of energy which replaces fossil fuels and the fact that paper and cardboard can be seen as a carbon neutral fuel. The authors mentioned that increased recycling necessitates an increase in fuel use for de-inking and re-pulping. As recycling mills in the UK use fossil fuels, whilst virgin paper mills (often in Scandinavia) use off-cuts and hydro-electricity the conclusion was that newsprint should be incinerated with the recovery of energy. They also stated that future improvements in the technology of recycling might change their conclusions.

The six articles that combine the use of LCA with other tools (such as CBA, Systems Analysis, financial models) (Leach et al. 1996; British Newsprint Manufacturers

Association 1995; Byström and Lönnstedt 1997; Craighill and Powell 1996; Petersen and Andersen 2002; Kärnä et al 1994) generally agree that the recycling of paper is not always the best waste management option. The fuel source for energy production and the substitution of this by energy from incineration seems to be the deciding factor. The sustainability of forest management is also important. Thus it seems that the combination of tools leads to changed perceptions about waste management. The generally accepted waste hierarchy, which puts recycling above incineration and both of these treatment methods above landfill (in terms of environmental benefit) is no longer as clear as originally thought. Byström and Lönnstedt (1997) stated that the *'waste management policy in a number of countries is characterised by a hierarchy of options in which waste minimization, reuse and recycling are all considered preferable to energy recovery which in turn is considered superior to landfill. The issues are highly complex and the science for assessing them, life cycle analysis (LCA), is still in its infancy.... Using the principle of LCA and a systems analysis approach simultaneously [give] alternatives to the hierarchy by looking at the whole system'*. Petersen and Andersen (2002) argued that paper could be incinerated to replace oil and coal as energy sources rather than using waste paper for recycling. However, the costs and benefits to a waste disposal authority of incineration were only more positive than recycling when waste paper prices were low, as the price gained for delivering paper to the recycling plant was then lower than the financial gain from the recovered energy.

Case studies are a method whereby the results can be checked using real-life scenarios, adding weight to their conclusions. Another study by Dahlbo et al (2006) used case studies to examine the compatibility of LCA and Social Costs analysis in order to tie the economic costs and environmental costs into the analysis. Costs Analysis assesses the cost to society of a particular project, i.e. health costs; possible deaths; costs to buildings through pollution. Using the city of Helsinki as a case study, the study found that the optimum treatment method for waste newspaper was to recycle 86% and incinerate the remainder if the recycling process used electricity from renewable sources. As other studies already showed, when recycling is based on the use of fossil fuels, incineration with energy recovery is the best option. In Scandinavia, where electricity is produced using hydroelectric power, the authors recommended recycling up to 86%, a figure at which the economic costs of recovery became too high to encourage further increase.

Byström and Lönnstedt (1997) maintained that the transport of recyclables could have a large effect on the environmental burdens if distances were large. However, this effect is still small in comparison to the emissions from the waste treatment options. Petersen and Andersen (2002) agreed on this point and the effects of transport were not included in their study either. This was supported by Dahlbo et al. (2005) when their LCA found that transport distances had only a small effect on emissions. Over longer distances there was a decrease in road freight and an increase in the use of trains for transport in Finland, where their study occurred. Increased recycling also lead to a decrease in the freight of virgin material and vice versa, so cancelling out many transport effects. From the above conclusions and the literature review in other areas, this thesis will use LCA as one of a combination of tools to determine the Best Practicable Environmental Option for paper waste management in isolated communities. The use of a modern computer based LCA will allow the inclusion of as many environmental factors as possible, which, combined with financial, social and legislative factors, give a complete analysis of the waste paper management systems being studied. The use of case studies will allow the experimental results to be compared to real case scenarios, strengthening the following findings.

The effects of transport on waste management in geographically isolated areas will be an important part of the research. LCA will determine the environmental effects of the added transport needed to take waste away from the area when there are no local facilities available and how important a part of the environmental burdens transport plays.

2.10 Multi-Criteria Decision Analysis (MCDA)

2.10.1 Introduction

The Department for Transport, Local Government and the Regions (2002) states that '*the main role of Multi Criteria Decision Analysis (MCDA) is to deal with the difficulties of handling large amounts of complex data in a consistent way*'. MCDA techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for later appraisal or simply to distinguish acceptable from unacceptable options. In addition, the social sustainability of waste management is regarded as important through the ethical behaviour of a waste management system towards society (den Boer et al. 2005). This means that the management of municipal waste in a responsible way for society is not just attaining the legislative targets and reducing financial cost; the acceptance of society towards a particular waste management option is also important. MCDA can incorporate social acceptance.

As a tool for decision-making, MCDA is suitable for research into local problems, such as the one covered by this research. The involvement of stakeholders is important for any waste management option to be acceptable to the local population and this involvement includes the passing of as much information as possible to them, to allow their decision-making to be as complete as possible. Kontos et al. (2005) stated that the final decision as to where to site an MSW facility is as much a political decision as a scientific one, strongly dependent on public opinion. The use of stakeholders, however, necessarily brings a certain level of subjectivity into the research, which needs to be considered. Waste management is a social problem. The waste is produced by society, needs to be dealt with by society and the placing of waste management and the types of waste management system chosen will affect society. Thus, neglecting the social aspects would clearly not cover these aspects of paper waste management. Van de Klundert et al. (2000) stated that '*including social, institutional, political and environmental concerns pays off in the long run in the form of greater sustainability of waste management systems. In the past many projects have failed due to an overemphasis on technical aspects alone*'.

The method for Multi-Criteria Decision Analysis follows the following steps (DTLR 2002):

- Definition of objectives for project or system,
- Establishment of measurable criteria to assess whether objectives have been achieved.
- Performance matrix or table, where options are plotted against performance within the criteria.
- The application of numerical analysis to the performance matrix. This can be a direct inspection of the matrix or can involve more complex mathematical models and/or computer models. The numerical analysis is usually in two stages:
    1. Scoring – The expected consequences of each option are given a numerical score, more preferred options scoring higher on the scale.

2. Weighting – Numerical weights are given to the options, with preferred options having a higher weighting.

- The scoring and weighting figures are multiplied together to give a final score for each option, which can then be ranked.

A key feature of MCDA is the emphasis on the judgement of the decision-making team in establishing objectives and criteria, estimating relative importance and judging the contribution of each option to each performance criterion

The advantages of MCDA are that it is open and easily understood by the local community, the objectives and/or criteria chosen for the analysis can be analysed and changed if they do not meet the objectives of the analysis and the analysis can provide important information for the decision-makers and the rest of the community about the decision-making process.

Renn et al. (2006) used a questionnaire to gain the opinion of 52 European experts and stakeholders and a survey and recommendations by Burgherr et al. (2005) looked at 28 social criteria for sustainable waste management. These were grouped into four categories; political, energy use of the system, social components of risk and quality of life. Hirschberg et al (2007) gave the following table of criteria (Table 2.7) which could be used in MCDA investigations.

The disadvantages of MCDA are the emphasis on the judgement of the decision-making team, where subjectivity can play a significant role (Burnley et al. 2005). This subjectivity means that the stakeholders involved might disagree on the ranking or weighting of different factors, the end result being a compromise. This could possibly allow the continuation of the status quo, rather than the choice of more radical solutions.

Criterion	
Environment	Resources Climate change Impact on ecosystems Waste
Economy	Impacts on customers Impact on the overall economy Impacts on the utility
Social aspects	Security of energy production Political stability and legitimacy Social and individual risk Quality of life
Legislation	European Waste Directives National Waste Strategies Local policies

Table 2.7. Criteria which can be used in MCDA panel workshops (Source Hirschberg et al (2007).

Chang et al. (1997) used MCDA to study different methods of solid waste disposal. The MCDA highlighted the trade-offs between the sometimes conflicting objectives of policy makers, e.g. low environmental impacts and low costs. However, the use of a quantitative scoring scheme allowed greater transparency into the advantages and disadvantages of the alternative SWM methods and helped conduct an informed debate about the most preferred method, so the authors supported the use of MCDA as a decision-making tool.

López (2010) used MCDA to examine energy-from-waste plants in a building development project in Reading. In addition to the techno-economic and environmental factors, Lopez' study included the opinions of local stakeholders on the technical, financial and environmental criteria, such as odour, noise, land availability, capital and running costs, pollution and climate change. Lopez concluded that the best option would be gasification with combined-heat-and-power. However, the author felt that the environmental impact information was difficult for the stakeholders to understand and they were more influenced by the economic credentials than the environmental factors. Thus the use of MCDA needs to involve the dissemination of information and the education of the participants for it to be fully valuable.

Kapepula et al. (2007) used MCDA in a study of household solid waste in the city of Dakar in India. The analysis produced three rankings in terms of the relative nuisance of the production, collection and treatment of waste within nine different areas of the city. The rankings aimed to discover which areas were best or worst in terms of nuisance, allowing the authors to suggest waste treatment methods which could solve the management problems in the city at that time. This ranking could be questioned because of the difficulty of finding sufficient, reliable and relevant data. However, with the use of field data, the authors proposed a set of remedies for waste management in the area, some general principles such as the reduction of waste at source and increased recycling and some local solutions such as government support for local groups of scavengers.

2.10.2 MCDA and paper waste management

This section examines the two studies identified that report on the use of MCDA in paper waste management (Table 2.8).

Author	Date	Subject
Bach et al.	2003	The generation and collection of paper waste.
Pati et al.	2006	Paper recycling

Table 2.8. MCDA and paper waste management.

Bach et al. (2003) looked at the logistics of the generation and collection of paper waste, while Pati et al. (2006) examined the paper recycling system. Both articles stressed the importance of the convenience of recycling facilities and the route and flow of waste paper through the system as important for reducing the environmental burden of the recycling system.

As mentioned earlier, there is no standard package for the use of MCDA. Bach et al. (2003) aimed to develop a model predicting the amount of waste paper that would be collected at regional levels in Austria, finding that the waste paper generation and the collection rate were dependent on purchasing power, family structure and employment within a municipality. The author admitted that his findings might not be true in other countries due to different demographics. The factors that influenced the collection of waste paper were important for the planning of waste paper treatment options in a particular area. Other authors have taken the amount of waste paper going into a management system as a constant, whereas Bach's research showed that the collection of waste depended on the convenience of collection systems and collection sites. The collection of data for an MCDA study is a problem and Bach et al. (2003) found that data on waste paper generation were difficult to find.

Pati et al. (2006) studied the paper recycling system in India, trying to find the optimum level for recycling when considering the financial costs and environmental burdens of a particular treatment method. The authors concluded that increased segregation at source to improve the quality of recycled paper and increased recycling to decrease environmental burdens were important factors, decreasing the amount of paper going to landfill. The model also aimed to help decision-makers in determining facility locations and the flow of different types of waste paper through the system.

2.10.3 MCDA and waste management in isolated communities

The use of MCDA in geographically isolated areas was shown to be useful in the study of Green Island in Taiwan (Chen et al. 2005). This method was used to incorporate the trade-offs between the sometimes conflicting interests of policy makers using quantitative scoring to allow the stakeholders to rank and score the different variables in the waste disposal systems. These scores were then compared to the scores of alternative systems. Chen suggested that MCDA allowed greater insight into the decision-making process and showed the advantages and disadvantages of the proposals to the public. The authors' analysis of the solid waste management options included the long-term costs of shipping waste to the mainland, which increased the advantages of building an incinerator plant, whilst short-term economic analysis concluded that the plant was not cost-effective. Long-term SWM costs also showed the changes in the life-span of the landfill site, the advantages and disadvantages of which could then be included in the debate and in policy-making. The conclusions of the study were that options which are more expensive in the short-term can often turn out to be cheaper and more beneficial in the long-term. In the case of Green Island, the (then) immediate introduction of recycling in combination with an incineration plant was the most cost-effective and politically acceptable option above the other two options considered; the sole reliance on landfill sites (business as usual) or the introduction of recycling alone.

Wen et al. (2009) used MCDA to examine how to develop policies for recycling and waste reduction in Taiwan, concentrating specifically on waste reduction. Social, economic and managerial factors were considered, supported by a case study in the county of Taoyuan. The study concluded that increased waste sorting was the optimum method for waste reduction. In addition, the authors suggested that the MCDA process could be used for other waste management decisions, due to the inclusion of social, economic and environmental criteria.

2.10.4 Rationale for MCDA use

As a result of the literature review into the use of MCDA, its advantages in the decision-making process and the incorporation of as many significant variables as possible, this thesis will use the technique to find the BPEO of paper waste management in isolated communities. This will allow the incorporation of social and political factors into the analysis which, together with financial, environmental and legislative factors will give as complete an examination of paper waste management options as possible. The fact that there has been little holistic research (such as the use of MCDA) into paper waste and specifically into paper waste in isolated communities means that this is an area of research which needs to be expanded.

2.11 The Best Practicable Environmental Option (BPEO)

BPEO is defined in the 12th Report of the Royal Commission on Environmental Pollution (HMSO 1988) as '*the outcome of a systematic and consultative decision-making procedure which emphasises the protection and conservation of the environment across land, air and water*'. The BPEO procedure establishes, for a given set of objectives, the option that provides the most benefits or the least damage to the environment as a whole, at acceptable cost in the long term as well as the short term. The term 'practicable' includes both the technical and the economic issues involved in the project, so the costs of the project must be taken into account in addition to the environmental benefits or damage (Burnley and Crompton 2003).

BPEO is a tool which '*should be used to consider the relative merits of various waste management options in the context of particular situations*' (DETR 2000). The environmental impact of waste streams will be influenced by the collection system, the geographical location of waste generation, management and disposal and the resources used. The determining of BPEO for a given waste product and area needs to consider the international obligations (such as EU Directives), the national policy framework and policy guidance at a local level.

The waste hierarchy has traditionally been used when determining the BPEO. The hierarchy states that landfilling is the least desirable option, recycling or recovery above, the re-use of products preferable to both and the reduction of waste being the most desirable option. However, researchers are now questioning the strict use of this hierarchy in all waste management policies, as geographic and demographic factors can mean that the hierarchy does not always result in decreasing environmental burdens (Forbes et al. 2004). It is argued that different materials in the waste stream should be dealt with by different processes; a range of options is preferable. The proximity principle is also included, suggesting that waste should generally be disposed of as near to its place of origin as possible (Waste Strategy 2000) due to the fact that the transport of waste increases the environmental impact and, as importantly, to prevent waste impacts being exported to other regions.

As discussed in Section 2.5, Scotland's first waste strategy acknowledged the need to take full account of local needs and circumstances in order to identify the best solutions for waste management across the country. In the process of finding the BPEO for waste management in Scotland, eleven Area Waste Plans were completed examining the environmental, social and economic impacts of different waste management options. Stakeholder involvement was a key part of the identification of BPEO, stakeholders being anyone with an active interest in waste management.

The BPEO for each waste area and, eventually, the BPEO for the whole of Scotland was based on the following principles:

- The waste hierarchy (see above) was used to guide choices between waste management options, with waste reduction being the highest preference for waste management,
- Proximity and self-sufficiency required waste to be dealt with as close as possible to where it was produced, with export to other countries only when shown to be the 'best solution',

- The principle of 'polluter pays' required that the producers of waste should bear the costs imposed by those wastes. The potential environmental and human health burdens of waste production, treatment and disposal should be reflected in the price of products and the charges made for waste management services.
- The Best Practicable Environmental Option amalgamated the preceding principles. The Strategy proposed that choices for waste management should be made in accordance with BPEO, which underpinned the development of Scotland's Area Waste Plans stating that '*the development and delivery of waste management systems and services which, with a high degree of planned efficiency and at an acceptable balance of costs and benefits, are capable of minimising the level and hazard of waste produced and maximising resource use efficiency and value recovery from wastes that are produced, whilst protecting the environment and human health*' (SEPA 2003 p20).

The 5th Framework Programme of the EU Commission published a report on waste management in island communities in Europe, covering Mallorca, the Isle of Wight, Sardinia, Gotland, the Shetland Islands and Guadeloupe (Islenet 2004). The report concluded that the BPEO for waste management on the six islands was the recovery of energy from waste. This was said to be due to the limited space available for landfill sites, the need to develop self-sufficient solutions to waste management because of the geographical separation from other areas, seasonal fluctuations in waste production due to tourism and the difficulty of recovering or recycling waste with the limited markets for products on the islands.

2.12 Summary of the literature review

As stated at the beginning of this thesis, there are few formal definitions of geographically isolated communities although the literature review supported the idea that geographical barriers lead to added problems for waste management, due to limited areas for landfill sites, isolated areas often having limited economic resources, the high transport costs to processing plants and the need to conserve the natural environment to support tourism and the local population.

The literature review covered the legislation for paper waste management in the UK, Scotland and Norway and from the review it can be concluded that although all three countries are governed by legislation from the European market and have, therefore, a minimum standard to which they must comply, there are differences in the methods the countries use to satisfy the legislative requirements. Norway is proactive in meeting waste management targets early and exceeding the amounts required. England, Wales and Scotland are often reactive, acting when forced by legislation to do so, but do comply with the Directives (Table 2.9).

From the literature review, it was shown that, although waste management in geographically isolated communities has been studied by a number of authors, the studies were either of one isolated community and the options for waste management for that community, or of one particular waste management option and it's suitability for isolated communities (e.g. incineration). There was a lack of studies on isolated communities as a group and the BPEO for waste management for one complete waste stream (e.g. paper). The studies that developed decision-making tools and models have developed these models on one particular community and there is no generic model to be used specifically for isolated communities based on in-depth studies of more than one such area.

The review of decision-making tools was to ascertain whether one particular tool would provide more reliable and objective information than others for the BPEO of waste paper management in isolated communities. The aim was to find a tool with a consistent and objective approach to assessing the environmental consequences of alternative management options.

Economic models can also involve the use of mathematical tools of greater or lesser complexity. This research will incorporate a simple mathematical tool to compare the financial aspects of different paper waste management options, using financial data collected from the case study areas. This will avoid the subjectivity of CBA, but allow the analysis to be easily comprehensible to stakeholders.

The review supported the idea that LCA would allow a systematic examination of a waste management option and its environmental impacts both up-stream and down-stream of the waste disposal unit. However, there is little, if any, literature that considers the combination of LCA with financial and social modelling techniques. I have decided to use LCA as a part of Multi-Criteria Decision Analysis (MCDA).

Country	BMW sent to landfill	MSW Recycled & Composted	MSW to Landfill	Packaging recycled
The European Union	206 – 75% of 1995 levels 2009 – 50% of 1995 levels, 2016 – 35% of 1995 levels	No specific targets	No specific targets.	2006 - 60% all packaging, 75% glass. 20% plastics. 2008 - 80% considered for all packaging.
The United Kingdom	4 years delay on the above targets	25% by 2005 30% by 2010 33% by 2015		
England and Wales		40% by 2010 50% by 2020	47% by 2010 25% by 2020	55% by 2008.
Scotland		40% by 2020	31% by 2020	
Norway	Total ban since 2004		25% by 2010 20% after 2010	

Table 2.9. The response of countries to the EU Directives on Waste.
BMW = Biodegradable Municipal Waste. MSW = Municipal Solid Waste.

Again, the review highlighted the lack of holistic research into waste management in geographically isolated areas and this research will cover some of these gaps. The thesis will take into account the social, political and local considerations within the decision-making process, in addition to financial and environmental factors covered by the LCA and the financial tool. The determining of BPEO for a given waste product and area should consider the international obligations, the national policy framework, and policy guidance at a local level. None of these factors can be considered by a financial model or LCA alone, but can be incorporated into MCDA. MCDA provides a holistic approach to the finding of the BPEO of paper waste management in isolated communities. This will be the basis for my thesis.

Chapter 3 Research Questions

3.1 Principal research question

Based on the summary of the literature review, the following main research question was identified.

Can the Best Practicable Environmental Option for paper waste management in isolated communities be identified by applying MCDA techniques to legislative, environmental, financial and other relevant information?

The reasons for choosing this research area are as follows:

1. Isolated communities, and their particular problems and challenges with waste management have not been considered holistically by previous research. The finding of the BPEO of paper waste management within such areas would be a valuable tool for local decision-makers, allowing the limitation of financial, environmental and social burdens to the communities involved.
2. The review of European Directives and national legislation in the UK nations and Norway showed that waste management policies target the reduction of biodegradable waste being sent to landfill sites as well as an increase in the recovery and recycling of waste. Paper waste is a biodegradable waste which, when landfilled, is broken down by anaerobic processes producing methane, a powerful green house gas. The landfilling of paper waste also contributes to the need for more landfill sites. Therefore, there is a need to find alternative paper waste management methods for all communities.
3. For the last decade, local authorities in isolated communities have shown a greater interest in solid waste management (Skordilis 2004). It is the local authorities which have the responsibility for the implementation of national and EU waste policy and it is the local authorities which face the financial and organisational problems within waste management, as well as the problems of community acceptance. This thesis will provide an aid to such decision-making.
4. The current use of incineration as a method of reducing waste sent to landfill sites in many island communities in Europe (Table 2.4) needs to be examined to ascertain whether this method gives the best practicable environmental option for isolated communities.

3.2 Subsidiary questions

The literature review has revealed key messages and key gaps, which will be examined by the following subsidiary questions:

1 Should the examination of paper waste be as a part of integrated waste management of all waste streams, or can it be examined successfully on its own?

Much of the literature stresses the importance of integrated waste management (IWM) based on the principle that there is no one solution to the waste problem and that a range of options should be considered whatever the waste type being considered or the geographical area. IWM involves the integration of the various waste streams into one management process and it has been shown that it is important that all the stakeholders in the waste chain are involved in developing and implementing solutions as part of an overall systems approach. (Lisney et al. 2003). Thus, IWM could be an important factor within the BPEO of paper waste management within isolated communities.

2 Would it be beneficial to have a waste management system which includes waste paper from industry and commerce?

In geographically isolated areas, 'industry' consists generally of small to medium enterprises (SME) which are generally not included in waste management policies (Lisney et al. 2003). The inclusion of waste paper from these sources could increase the supply of waste paper, allowing alternative methods to become economically viable and decreasing the overall burden to the environment from paper waste management in isolated communities.

3 What are the specific economic problems for isolated communities and the management of paper waste?

In geographically isolated areas, the economic limitations for a local authority might put constraints on the methods of paper waste management chosen. Are there specific economic aspects of isolation which could be alleviated by changes in the waste management options chosen?

4 *How does the increased separation of paper waste affect the BPEO of isolated communities?*

The separation of paper waste at source makes the resource cleaner and easier to deal with than when it is in mixed waste. However, the need for cleaner, separated waste is dependent on the participation of householders and the waste management options available. Thus it is necessary to look at the collection methods, together with the treatment methods currently in use for paper waste and whether these should be changed.

5 *Could the techniques in this research help isolated communities to become more pro-active as regards the European Union's increasing demands for waste reduction and resource conservation as well as contributing to the sustainable use of paper resources?*

The aim of the research is to find the Best Practicable Environmental Option for waste paper management in isolated communities. The national legislation within England, Scotland and Norway has been developed in response to the European Directives. The aim within the UK and Norway is to develop waste management strategies that allow the options to be as environmentally sustainable as possible. Within sustainability it is necessary to apply the principle of BPEO to reduce the environmental burdens as far as possible, within reasonable financial burdens (Burnley and Crompton 2003). Thus the finding of this research could allow them to be proactive, rather than reactive to future legislation from the European Union.

6 *Is there a viable market for recovered paper from isolated communities?*

For the recovery of paper to be a part of BPEO in isolated communities, there needs to be a viable market. This research will try to find a method whereby the effects of transporting waste paper and its products across the geographical boundary can be minimised and/or the possibility of local solutions to the treatment of paper waste.

Chapter 4 Methodology

4.1 Introduction

This section describes the tools used in the research to examine the financial, environmental and social effects of paper waste management in isolated communities. The choice of tools is based on the literature review and the advantages and disadvantages found in the use of the tools. There will be financial and environmental assessment for the three case study areas combined with a stakeholder panel for assessing social criteria on the Isle of Wight.

As mentioned in Section 1.5, the thesis aims to make methods and data understandable to any stakeholders who wish to use them in their decision-making process. Therefore, the research methods used are kept as simple as possible, whilst maintaining the necessary degrees of professional and academic rigour.

4.2 Case studies

The use of case studies, as mentioned in Section 3.9.2, is useful to compare theoretical results with actual results. This gives models greater credibility and if the theoretical and actual agree, the possibility of extrapolation to other similar areas.

Three isolated areas were chosen as case studies for the research; The Isle of Wight in Southern England, The Shetland Islands in Scotland and Nordfjord on the west coast of Norway. These three areas were chosen as they are all required to implement the EU's waste and related Directives, they are separated from other communities by significant geographical barriers, all have a large enough population and tourist population to make waste management an important issue and they collect the waste statistics necessary for such a study.

Geographical and demographic data were collected from the local council web-sites. Waste data were collected from annual reports from the waste authorities, from Wastedataflow UK (2010) for the two UK areas and from interviews with public and private sector waste managers in Nordfjord and the Isle of Wight.

4.3 Financial analysis

The Organisation for Economic Co-operation and Development (OECD 2006) stated that '*The OECD has long championed efficient decision-making using economic analysis*'. Thus, the inclusion of a financial model in the finding of the Best Practicable Environmental Option for paper waste management in isolated communities is necessary. Without a good assessment of financial costs any decision-making will be weakened or, at worst, ignored. On the other hand, any consideration of economic cost without environmental assessment could be damaging to the local environment. It is often true that smaller, isolated communities such as the Isle of Wight, the Shetland Islands or small coastal communities like Nordfjord in Norway have a poorer economy than larger, heavily populated areas. This makes the consideration of economics important in any decision-making process in isolated communities, together with the consideration of environmental factors and social factors.

It would be possible to estimate the cost of a particular waste management system from first principles; determining the capital and operating costs of the major plant items, labour costs and income from power sales etc. However, such cost models can be unnecessarily complex while neglecting specific local or commercial factors that can influence costs. Furthermore, waste management costs are becoming more transparent in the UK through the introduction of Wastedataflow. Therefore it was decided to base this analysis on actual waste management practices and costs in the UK and Norway. The financial data consisted of collection costs, road and sea transport costs, and gate fees. The gate fees reflect the capital and running costs of a treatment process and also take account of income from material and energy sales and residue disposal landfill charges.

4.4 Life cycle assessment

Two LCA packages were considered for this study; WRATE and SimaPro (See Glossary and Section 2.9.1). SimaPro has been widely used for LCA and includes several inventory databases, but was developed for use in all kinds of situations, whereas WRATE is specific to waste management. WRATE covers all parts of the waste management system from collection to treatment and contains LCA inventories for specific waste management activities (waste collection vehicle manufacture and use, incinerator construction and operation and offsets from compost/ digestate use). WRATE also includes the capital burdens associated with the specific waste management option, which are generally insignificant compared to the rest of the system, but allows the emissions from the production of building materials to be included. WRATE also includes the capital burdens of the collection vehicles, wheelie bins and refuse sacks used in collection and transport of waste.

With all these factors in mind, WRATE was chosen as the best LCA tool for use in this research.

WRATE was used to model current and theoretical scenarios for waste management in the three case study areas, both for the complete waste stream and for the paper and card waste stream. The complete waste stream was also compared to a mainland area (Portsmouth UK) to assess the importance of the geographical barrier to environmental factors. The current complete waste stream was compared to sending all waste to recycling, all waste to incineration/gasification, all waste to landfill and all waste to composting. It was recognised that some of these options are neither practical nor economically sound, but as theoretical scenarios they are useful in assessing the current waste management options from an environmental standpoint. WRATE was then used to compare the waste paper stream in a similar way.

The sources of data used in the WRATE modelling are discussed in Chapter 7, but in summary, waste data were obtained from Wastedataflow, annual local authority reports and from local knowledge. WRATE's internal databases were used for data on waste collection and processing emissions.

4.5 Multi-criteria decision analysis

As discussed in Section 2.10 the main role of Multi-Criteria Decision Analysis (MCDA) is to deal with the difficulties of handling large amounts of complex data in a consistent way. The BPEO of paper waste management in isolated communities includes the examination of environmental, financial and social factors, which are complex, subjective and varied. I have therefore chosen MCDA as the optimal method for analysing all these variables. MCDA is potentially a very valuable tool in that it can bring together a combination of all the other tools into one study. This could allow a variety of stakeholder groups to agree on a particular project or decision. However, none of the reviewed research in the literature review into paper waste management has used MCDA in combination with other tools. Thus, this research, where LCA, an economic tool and MCDA are combined is covering new ground. The MCDA examination will also discuss whether this is a valid tool for the incorporation of social factors into the decision-making process.

Due to my being a resident on the Isle of Wight, it was decided that the most practical method of incorporating these aspects was a multi-criteria decision analysis panel of people from the island. The results of the panel would then be used in the analysis of the Isle of Wight and as an indication of the likely results if applied to the other two communities. This extrapolation of results will not be perfect, because as explained later (Section 9.7) panels from other communities, consisting of different stakeholders, with a longer time span for the workshop and more participants could give varying results to those found on the Isle of Wight. However, with the restraints of time and finance within the research, the one set of findings are used to give an idea of local residents' ideas on the importance of the various paper waste management options.

The panel members were selected from the public sector, from the local waste management company, from environmental groups and from local residents, with varying age ranges, gender and the inclusion of ethnic minorities (Table 4.1). The members were first contacted by letter and then, for those who gave a positive response, by telephone.

Person	Gender	Age range	Occupation	Link to the Island
1	F	50-60	NHS admin	Visitor
2	F	20-30	Environmental student	Lives locally
3	M	20-30	Environmental student	Lives locally
4	M	40-50	Wildlife trust Reserve Manager,	Lives and works locally
5	F	40-50	Waste management company Community Liaison Officer	Lives and works locally
6	F	30-40	Senior Probation Officer	Lives and works locally
7	F	60-70	Wildlife trust Chair of Residents' Group	Lives locally
8	M	60-70	Retired	Lives locally
9	M	60-70	Retired	Lives locally

Table 4.1. MCDA panel participants

The process involved examining the findings of WRATE, assessing emissions, energy and resource use and the economic model. In addition, five broad social factors were chosen which were weighted by the panel members.

The MCDA workshop was set up specifically to look at the social aspects of paper waste management on the Isle of Wight. Two introductory presentations were made to the panel: the first covered the aims of the research and the findings from the previous phases (legislative review, financial assessment and WRATE LCA research). The second covered the technical aspects of the waste management options available, the national legislation and targets for waste in England and the use of LCA. One of my supervisors (SJB) was available throughout the workshop to answer any questions about the technical aspects of paper waste management.

The objectives for the workshop were to rank paper waste management options in terms of the following criteria:

- Impacts on the environment,
- Impacts on human health,
- Jobs on the island,
- Cost,
- Social acceptability,
- Tourism,
- Legislation and national targets.

These criteria were chosen as a result of the literature review (Table 2.7).

The workshop was divided into two groups, each with a similar mix in terms of gender and age. Each group then debated the above criteria, allocated weightings to each and assessed their importance in relation to each other. The social factors that were considered more important by the panel members were given higher scores than those that were considered less important. All the weighting scores added up to 100.

Once the weighting scores were confirmed, each group then ranked the following paper waste management scenarios:

- Newspapers and magazines to recycling; the rest to gasification (current practice),
- All paper to landfill on the island,
- All paper to gasification on the island,
- All paper to recycling on the mainland,
- All paper to recycling on the island (build a paper mill),
- All paper to composting (with garden waste),
- All paper to incineration on the mainland (with general municipal waste).

It was made clear to all participants that this was a somewhat artificial situation and, in reality, paper waste would be managed along with the rest of the municipal waste stream. However, concentrating on paper allowed participants to focus on a particular set of issues.

Each option was considered against each social criterion and ranked from best to worst, the highest possible score being 7, the lowest being 1. Two options could be considered of equal rank, in which case they were given equal scores.

When the two groups had finished their discussions, they came together and the results were transferred to a spreadsheet, with the weighting scores multiplying the ranking for each social criterion and each waste management option.

The workshop covered a period of three hours, with the presentations covering one hour and the two workshop sessions the rest of the allotted time.

4.6 Summary of methodology

The research will be based on Multi-Criteria Decision Analysis, with an economic model developed during this research using data obtained from the literature review, the use of WRATE for the environmental life cycle assessment and a MCDA panel workshop to cover the social criteria.

Chapter 5 Results and discussion – Case studies

5.1 The Isle of Wight, Southern England

The Isle of Wight is an island off the south coast of England. It has a geographical area of 381 square kilometres and a resident population of 138 500 (2007). It is separated from the mainland by a stretch of water called the Solent, with a distance of 4.8 km from Portsmouth on the mainland and 8 km from Southampton on the mainland.

Island Waste Services Ltd., a daughter company of Biffa, is contracted by the Isle of Wight Council to manage waste on the island, collecting, treating and transporting all MSW on the island (Island Waste 2005). Island Waste operates a resource recovery facility (RRF) for MSW collected. This produces 'floc' pellets, originally for use in the adjoining waste incineration plant. However, in 2002 this arrangement was terminated due to a lack of agreement about gate prices for the pellets. The incinerator stood idle for five years, but during 2007/8 the plant was re-opened as an ENERGOS gasification incinerator using money from the UK Department for Environment, Food and Rural Affairs (Defra) as part of their New Technology Demonstrator Programme promoting new ways of reducing biodegradable waste being sent to landfill. The plant cost £8 million to develop and operate in the first year, of which Energos provided £4 million, Defra £2.7 million and Island Waste £1.3 million.

The gasification plant is the first of its kind in the UK and, alongside the gasification equipment investment is also being made at the Isle of Wight Council's Resource Recovery Facility (Isle of Wight Council 2008). The new facility extracts recyclable material from waste delivered to the site, with the residual waste being processed to provide fuel for the gasification plant. The diversion rate away from landfill is currently 56% and expected to increase to 65% when the plant is operating at full capacity. A further increase to 75% would be possible if a wood shredder was installed, so the plant could process this waste as well (Isle of Wight Council 2008).

The 2.3 MW plant processes the refuse derived fuel (RDF) at the rate of 30 000 tonnes per year which is used to produce 15 600 MWh electricity for export to the grid each year. The additional benefit for the incineration company is that the electricity qualifies for Renewable Obligation Certificates as the ENERGOS process is an advanced conversion technology. This process produces emissions well below the Waste Incineration Directive limits.

Prior to the opening of the gasification plant the RDF pellets were sent to Aylesford in Kent (Castle Cement Works) for use as fuel in cement kilns.

There is one major landfill site on the island, Standen Heath (about 5 km east of Newport), which opened in April 2000 with 1 629 000 m³ of void space (Island Waste 2005). The site is expected to be full by 2015 at the current disposal rates and the council is looking to open a new site in 2015. Standen Heath landfill site is base lined with a metre of compacted clay covered with a 2mm thick liner. A layer of sand protects the liner and only 'soft' waste is placed directly on the sand.

Leachate is collected and pumped to a treatment plant on site, where ammonia and chemical oxygen demand (COD) levels are reduced, before being discharged under consent to Southern Water's foul sewer. Methane and CO_2 emission levels are minimized by the application of cover, engineered capping, gas extraction and the flaring of methane. Through modelling, using the Environment Agency's model Gassim, it was estimated that 13 417 tonnes of CO_2 were emitted from the site between 2004 and 2005.

The paper fraction of the MSW is currently separated into two management systems. Newspapers and magazines are collected from private households by a kerbside service every second week, using a 3.5 tonne capacity truck. These are sent to Portsmouth for bailing and then on to Kent for recycling; 40-45 tonnes per week are recycled (Island Waste 2004). All other paper from private households is incinerated with the general waste.

All commercial and industrial paper from small-to-medium enterprises is incinerated via the RRF. Only large firms with an annual turnover of over £2.5 million are obliged by law to separate their paper waste.

5.2 The Shetland Islands

The Shetland Islands are situated 160 km north and slightly east of the mainland of Scotland. Most of the inhabitants live in the areas of Lerwick and Scalloway.

Agriculture and fishing are important industries as well as aquaculture and knitwear manufacture. In summer, tourism is particularly important and causes a large increase in population and economic turnover. The population on Mainland Shetland is 17 550 (2001).

The Shetland Islands have a relatively self-contained waste management system based on landfill and the waste to energy plant in Lerwick. Other than a small number of relatively small-scale private contractors (predominantly inert landfill operators) there is little private sector involvement in waste management in the islands. The provision of waste management services is dominated by the area's local authority (Shetland Islands Council, which has responsibility for MSW, commercial and industrial waste (Evans 2003). Figures from the Scottish Environment Protection Agency (SEPA) show that 11625 metric tonnes of MSW were produced annually in the Shetland Islands (2003). Most of the MSW collected by the authority is recovered as fuel for district heating via the incinerator in Lerwick (around 64% or 7500 tonnes per annum) which provides district heating for up to 1000 homes. The facility has an estimated maximum annual throughput capacity of 22 000 tonnes.

The geographical fragmentation and remoteness of the islands, and their highly dispersed human populations, mean that waste collection and transport, for kerbside recycling in particular, are less practicable and more costly than mainland areas. For this reason the Area Waste Plan concluded that kerbside recycling collections should be targeted at the more densely populated areas (SEPA 2003).

5.3 Nordfjord in Western Norway

The area of Nordfjord on the west coast of Norway includes six boroughs and has a geographical area of 4295 square kilometres and a resident population of 32 965. Nordfjord is surrounded by high mountains and is situated along 110 km of Nordfjord, an arm of Sognefjord. It is also geographically isolated by the North Sea. The area is economically dependent on tourism, fishing and small local farms.

The local authorities employ Nordfjord Miljøverk IKS (NoMil) for the collection and transport of all municipal waste in the area. The company is owned collectively by the boroughs of Brenanger, Eid, Gloppen, Hornindal, Selje and Stryn.

There are plans to build a waste incinerator in the area (Byrkjelo), although this is still in the early stages. In 2009, Norway instituted a ban on the landfilling of all biodegradable waste, including paper.

8690 tonnes of municipal waste were collected in 2005, with this decreasing to 8297 in 2006 (NoMil 2006). Due to the above ban on the landfilling of biodegradable waste, none of the waste paper from MSW is sent to landfill. NoMil have a contract with Tenden Container og Gjenvinning for the management of the collected paper waste. 1163 tonnes of paper were collected in 2005 and 1267 tonnes in 2006. Clean and dry white paper is baled and sent as recycled paper to Norway's largest paper company, Norske Skog. Cardboard and brown paper (packaging) is sent to Pettersen's recycling factory in Fredrikstad, in southern Norway.

Paper is separated by the house-owners into one container. This container holds all kinds of paper; reading materials, packaging and cardboard. It is collected once a month and taken to a collective sorting depot in Stryn. There are two types of collection vehicle; side-loading vehicles, with a mechanical arm to lift the containers and one technician on board for rural areas and rear-loading vehicles with extra staff to load in residential areas.

The residual waste is transported to Sweden where it is burned in a district heating plant. Although this measure involves transporting the waste 900 km by road, it is still the cheaper option due to the Norwegian incineration tax. This practice also appears to breach the "proximity principle", but in discussions NoMiL and local authority staff did not see that this was a problem. Table 5.1 shows the percentages of waste recycled, incinerated with energy recovery and landfilled in the period 2004 – 2006.

Waste management method	**2004**	**2005**	**2006**
Recycling	29%	34%	44%
Incineration with energy recovery	0%	36%	37%
Landfill	71%	30%	19%
Total	100%	100%	100%

Table 5.1. Recycling incineration and landfill in the Nordfjord district, Norway. Source: Statens Forurensningstilsynet 2008.

5.4 Summary of the case studies

The case studies have been chosen as examples of geographically isolated communities within the European Union; governed by the EU Waste Directives but with different national and local solutions to the management of paper waste. All three areas are separated from the rest of the country by geographical barriers, although the distances and type of barrier differ. There is also a difference in the legislation governing these three areas and this needs to be taken into account when comparing their solutions to paper waste management.

In Chapters 6-9, these case study areas will be used to examine actual and theoretical management scenarios to try to ascertain the BPEO for each and whether this is affected by the differences between the areas.

Chapter 6 Results and discussion – financial model

As mentioned in Section 4.1, one aim of the research is to provide a working tool which is easy for non-specialist stakeholders and decision-makers to use. Thus, the choice of the financial model is to a large extent determined by this aim, with transparent data, which are easily understood and avoiding the use of complex mathematical models.

Obtaining accurate and meaningful data on the cost of the different stages in the waste management chain is difficult to achieve. Whilst all UK local authorities publish headline costs of waste collection and disposal in £ per tonne and £ per household through Wastedataflow these figures are not broken down into the different stages in the management chain. For example, it is not possible to separate the costs of collecting residual waste and kerbside recycling collections.

The waste management industry regards capital and operating costs as commercially sensitive which is understandable. Furthermore, the costs that they would quote to a local authority would depend on several factors such as their assessment of the likely competition, the desire to establish a demonstration of a particular technology and the company's long-term strategic aims.

Discussions with a former employee of the UK's (then) Department of Trade and Industry's Energy Technology Support Unit (ETSU) revealed that plans to pay waste management companies to provide costings for a range of incineration processes had to be abandoned due to the industry's unwillingness to take part.

Therefore, the costs discussed below are taken from the academic and trade literature, discussions with local authorities, data from industry outside the waste sector and from first principles.

6.1 Waste Collection costs in the UK

Hummel (2002) carried out a questionnaire and interview survey to obtain data on the cost of the collection of dry recyclables, green (compostable) and residual waste in England under a number of different waste management scenarios. The most important aim of her research was to allow comparison of the various available treatment options from a financial perspective. The collection systems evaluated included both bring and kerbside collections. The results are summarised in Table 6.1.

Collection	Mixed waste kerbside (weekly)	Paper kerbside (fortnightly)	Green waste kerbside (weekly)	Dry recyclables bring sites
Cost (2000)	22	132	67	22
Projected Cost (2007)	21	86	112	33

Table 6.1. Average collection costs for various waste collection scenarios in England, £/tonne. Source: Hummel 2002.

As Hummel states, there are a number of assumptions in the data which must be taken into account:

- The data are collected from all over England, with different authorities operating different collection routines. These have been assumed to be the same routines,
- Data were dependent on the reliability of the reports coming from the different local authorities,
- The costs do not include overhead or management costs.

When projecting the costs for 2007, the following assumptions were made, in addition to the assumptions noted above:

- Any possible change in the composition of household waste was ignored,
- It was assumed that the composition was the same for every household,
- That the waste amount from each household grew at the same rate.

The above assumptions may affect the overall costs and discrepancies may well occur in the figures quoted. However, these discrepancies will be the same for all the scenarios examined in this research, so should not affect the comparison of different waste treatment collections.

The fact that the collection costs were predicted to decrease in 2007 is assumed to be due to the larger amounts of waste collected from each household and the higher efficiency of collection vehicles and collection methods, which reduced the cost per tonne of collection in some cases.

In a more recent study, Hogg et al. (2009) estimated waste collection costs in the UK to be of the order of €60 (£53.4) per household. Applying Hummel's 2007 data from Table 6.1 to the materials collected shown in Table 7.1, gives a total collection cost of £29.28 per tonne or £42.33 per household which compares well with Hogg's values.

Wastedataflow quotes the overall net cost of waste collection on the Isle of Wight as £43-£46 per household over the period 2006-2009. As stated above, the Wastedataflow values are not broken down by collection scheme (residual waste, kerbside collections etc), but the figures do compare well with Hummel's data. Therefore it was concluded that Hummel's data were sufficiently reliable to be used in this research.

6.2 Road Transport costs

The costs of transporting bulk waste around the country are high and are an important part of any financial model for use in waste management decision-making, particularly when considering isolated communities. Due to the long-term nature of waste management projects, capital costs are far out-weighed by running costs. Local Government Infrastructure Services stated that 70% - 90% of the life-time costs of a transport project are the running costs (LGIS 2010) so it is these that will be included in the examination of paper waste management options in isolated communities.

A report produced by Forward Scotland (2005) used costs models to simulate waste haulage by road, rail and sea. The transport of all waste by road scenario found that between 2002 and 2020 a total of 326.4 million tonnes of waste would be transported at a cost of £386.4m (£1.184/tonne). The average cost of transporting each tonne of waste one mile would then be 5.6p, which is 3.5p/km.

The Road Haulage Association (2009) publishes a guide to the cost of operating a range of transport vehicles. For a 32 tonne gross weight vehicle the road costs were 68.3 p per mile (Table 6.2). The fixed costs per day (depreciation, licensing, employment etc.) were found to be £263 and at an average of 320 miles per day this is 82 pence per mile, or 51p/km. It is assumed these vehicles carry 17.5 tonnes of waste, so the overall running costs are 8.5 p/tonne-mile (or 5.4 p/tonne-km).

Time related costs (£/year)	
Driver employment	28 500
Depreciation	14 200
Licences	1 200
Vehicle insurance	2 830
Goods in transit insurance	330
Interest on capital (6%)	2 560
Overhead per vehicle	13 940
Total (£/year)	£63 560
Total (£/day)	£263
Mileage related costs (£/mile)	
Fuel	48.7
Tyres	4.9
Repairs and maintenance	14.7
Total	£0.683
Total cost assuming 320 miles per day	**£1.50/mile**

Table 6.2. 32 tonne articulated vehicle operating costs (RHA, 2009)

Allowing for inflation and the fact that the Forward Scotland data are for the public sector, whilst the RHA data are for the private sector, the two figures are similar. The figure used in this research will therefore be the figure from RHA.

The waste scenarios involve different transport distances for the Isle of Wight and for the Shetland Islands (Table 6.3). The Shetland Islands has a local incinerator, landfill site and composting plant and the Isle of Wight has a gasification plant, composting plant and landfill site, so the transport mileages to these sites will, for the purposes of this investigation, be zero. The distances to the paper recycling plants represent transport to Kent from the Isle of Wight and from Aberdeen to Chesterfield in Derbyshire for the Shetland Islands. For this exercise, it is assumed that the Isle of Wight waste would be transported to the incinerator in Portsmouth and the Shetlands gasifier would be a local plant, as it is impractical to send all the waste to the south of England as this is currently the only gasifier in the UK.

Scenario	**Landfill site**	**Gasification plant**	**Recycling plant**	**Composting plant**	**Incineration plant**
Isle of Wight	0	0	314	0	25
Shetland Islands	0	0	450	0	0

Table 6.3. Distance travelled by collected wastes to the processing plant (km).

Each distance is multiplied by 5.4p to give the cost of transporting 1 tonne of paper waste to the treatment (Table 6.4).

The Isle of Wight disposed of 21,351 tonnes of paper and card in 2008, the Shetland Islands disposed of 6,370 tonnes of paper and card in 2008. The current waste paper treatment scenario on the Isle of Wight is 2,828 tonnes of newspaper and magazines to recycling and 18532 tonnes of paper and card to gasification. Thus 87% of paper is gasified and 23% recycled. The costs of sending this proportion of paper to recycling will therefore be 23% of the cost of sending all paper to recycling. In the same way, the Shetland Islands recycled 113 tonnes of their 6370 tonnes of paper waste under the current scenario, which is 2%. The other costs are for 100% sent to the various treatment options.

Paper waste (t)	Current	100% landfill	100% gasification	100% recycling (m)	100 % composting	100% incineration
Isle of Wight	3.89	0	0	16.95	0	1.35
Shetland Islands	0.48	0	0	24.30	0	0

Table 6.4. The cost of road transport for various paper waste scenarios for the Isle of Wight and the Shetland Islands (£/tonne).

6.3 Sea transport costs

Both the Isle of Wight and the Shetland Islands have the added financial cost of transporting their paper waste to the mainland for any treatment that they cannot cover themselves.

A commercial operator (Freight Link Solutions Ltd, 2010), quoted the cost of taking an articulated lorry from the Isle of Wight to Portsmouth to be £190 each way, so a total cost of £380. If it is assumed that the paper waste is being transported in 20 tonne loads, then the resulting cost is £19 per tonne. For the Shetland Islands, the taken sea route is from Lerwick to Aberdeen and the same company quoted a price for a 20 tonne payload lorry on a freight service ferry of £729.73 one way, which means the total cost is £1459. The price per tonne waste will therefore be £72.95.

6.4 Processing facility gate fees

The literature review also revealed a lack of complete financial data for the costs of building and running of waste treatment plants (European Commission 2003). Therefore, it was decided to use the overall gate fees as representative of the capital and running costs of a plant. The gate fee is the payment received by the treatment company to accept the waste from the waste authority, which reflects the cost of processing the waste, the capital and running costs of the plant and any revenue acquired from materials recovery.

The gate fees for the different waste management options are given in Table 6.5 and are from two different sources, as WRAP had not included gasification treatment plants in its survey (WRAP, 2009; Juniper Consultancy 2008). The negative figures for the MRF gate fees are when local authorities receive money for their waste rather than paying a gate fee.

Waste treatment	Grade/material/type of facility	Median (£/t)	Range (£/t)
Materials Recycling Facility	Pre 2010 Post 2010	£15 £4	-£36-£85 -£30-£63
Composting	Open-air windrow In-vessel	£24 £43	£6-£51 £29-£82
Landfill	Gate fee Gate fee plus landfill tax	£20 £76	£12-£55 £68-£111
Incineration	Pre 2000 Post 2000 facilities	£54 £73	£35-£79 £54-£97
Gasification	30 000 tonnes fuel	£75	£60-90

Table 6.5. Gate fees for waste treatment in the UK (£/tonne). Source: WRAP Gate Fees Report 2011.

Cooke (2010) developed a spreadsheet model for use in teaching waste management which included data on landfill gate fees. These fees were calculated from first principles using data supplied in the former Department of the Environment's Waste Management Papers (DoE, 1995). Exclusive of VAT, Cooke derived a figure of £24 for landfill charges excluding any landfill tax, which corresponds with WRAP's gate fees.

Gasification gate fees were examined by the European Commission (2006) and found a range of £35-80 per tonne. With inflation, this range corresponds to the figures from the Juniper Consultancy.

6.5 Norwegian collection costs

Collection costs for waste in the Nordfjord area of Norway are partly covered by the residents themselves, with their contribution to waste disposal costs being part of the local council tax, which is billed for the separate items covered by the tax (NoMil 2010). In 2006, local taxation included a ring-fenced amount for collection of £250-£350 per household (based on an exchange rate of NKr 8.76 = £1). In the same year, households produced an average of 1035 kg waste per year (Statistisk sentral byrå, 2010), so the collection costs were £209/tonne/year, which is £8 per tonne. Residual waste is collected with green waste the first week and paper/card is collected with plastic and green waste the second week (NoMil 2010). This means that the cost of collecting separated paper and card will not differ significantly from the collection of residual or mixed waste. However, the cost of collecting organic waste weekly will be approximately twice as expensive.

6.6 Norwegian transport costs

The costs of transporting waste in Norway are taken from Dijkgraaf et al (2001) where it was calculated that transport over a distance of 600 km cost €32/tonne, which is the equivalent of 7p/tonne-mile. This is similar to the costs calculated for transport in the UK (5.6p/tonne-mile).

Mixed waste from Nordfjord is transported by road to an incinerator in Uppsala in Sweden, a distance of 560 miles. This is due to the high gate fees at the two incinerators in Norway, in Bergen and Ålesund (See Table 6.6). In Sweden, the gate fees are £50 per tonne (Dagbladet.no 2009). Separated paper and card are transported to Lysaker in Norway for recycling, a distance of 280 miles. Compost is transported to Sogndal in Norway, a distance of 84 miles.

For the current scenario, (NoMils, 2006) the total household waste collected in Nordfjord in 2006 was 8297 tonnes. If it is assumed that 33% of this waste is paper and card, then the total paper and card disposed of was 2738 tonnes. The separated paper and card sent for recycling was 1267 tonnes, which is 46% of the total.

6.7 Norwegian gate fees and taxes

There are few data in the literature for gate fees in Norway. In addition, the sending of biodegradable waste to landfill has been banned since July 2009, so there are no costs given for this option.

The Norwegian state has a more widespread system of taxation on waste treatment than is found in the UK and the costs of using different treatment options are affected by these taxes. The taxes are increased on older, less efficient waste treatment plants and on the acceptance of more hazardous waste. However, there are no exact figures given for them in the literature, apart from incineration (Table 6.6). As mentioned in Section 6.6, the fact that Sweden does not have the same tax means that waste is sent to Sweden for incineration, even with the added costs for transportation. The gate fees for incineration in Sweden are £25-£60 (Sundberg 2009). As there are gaps in the data for gate fees for recycling and gasification, I will assume that the Norwegian gate fees are slightly higher than the UK gate fees, consistent with the slightly higher costs of incineration and composting (as there are no gasification plants currently operating in Norway, the gasification scenario is theoretical). These figures are given in red in Table 6.6.

Waste treatment option	**Incineration in Norway**	**Composting**	**Recycling**	**Gasification**	**Incineration in Sweden**
Gate fees (£/tonne)	90-120	50 - 70	30	95	25-60

Table 6.6. Taxes and gate fees in Norway. Source: Statens Forurensningstilsynet 2004; Oloffson 2004.

6.8 Summary of the results of the financial model

To summarise the total costs of managing paper waste for the three areas based on the model are given in Tables 6.7, 6.8 and 6.9.

Treatment option	Current (23% recycled 87% gasified)	100% landfill	100% gasified	100% recycled	100 % composted	100% incinerated
Collection	38	21	21	86	112	21
Sea transport	4.40	0	0	19	0	19
Road transport	3.89	0	0	16.95	0	1.35
Gate fees	68.7	20	75	15	43	73
Landfill Tax		56, max £82 in 2020				
Ash disposal	27.84	0	32	0	0	32
Total	**142.83**	**97 (122 in 2020)**	**132**	**148.63**	**155**	**146.35**

Table 6.7. The total cost of paper waste scenarios on the Isle of Wight. £/tonne.

As Norway has a ban on sending organic waste to landfill, this is not included in Table 6.9. The current scenario includes sending waste to Sweden for incineration. I have included calculations for the incineration of waste at the nearest Norwegian incinerator, to be able to compare this to the current practice of sending waste to be incinerated in Sweden. The closest incinerator is in Vågseidet, north of Bergen, a distance of 171 miles by road. A hypothetical scenario using the gasification of paper waste would require a road transport distance of 502 miles, to Stavanger on the south-west coast.

Management option	Current = 2%recycle 98% incinerate	100% landfill	100% gasification	100% recycling	100 % composting	100% incineration
Collection	22.30	21	21	86	112	21
Sea transport	1.46	0	0	72.90	0	0
Road transport	0.48	0	0	24.30	0	0
Gate fees	71.84	20	75	15	43	73
Landfill tax	0	56/82	0	0	0	0
Ash disposal	31.36	0	32	0	0	32
Total	**127.14**	**97/112**	**132**	**98.2**	**155**	**126**

Table 6.8. The total cost of paper waste scenarios on the Shetland Islands. £/tonne.

Manage-ment option	Current = 46%recycle 54% incinerate	100% gasify	100% recycling	100% composting	100% incineration in Norway	100% incineration in Sweden
Collection	8	8	8	16	8	8
Sea transport	0	0	0	0	0	0
Road transport	30.19	35.14	19.6	5.88	11.97	39.2
Gate fees	38.1	95	30	60	105	40
Total	**76.30**	**138.14**	**57.4**	**81.88**	**124.97**	**87.2**

Table 6.9. The total cost of paper waste scenarios in Nordfjord, Norway. £/tonne.

6.9 Review of the financial model

- The total costs of managing waste paper on the Isle of Wight were compared to costs publicised by Island Waste on Wastedataflow, which were £56-63/tonne for disposal and £43-46/tonne for collection. The total costs being therefore £99-109 compares well with the above value in Table 7.6.
- As mentioned earlier, there are gaps in the financial data available from Norway for the gate fees of recycling and gasification. However, even if these gate fees were 20% higher, the costs of recycling and gasification would still maintain recycling as the cheapest option and gasification as the most expensive.
- The financial data are collected from different years. The data for collection are from 2002 and the gate fees from 2010. However, each waste management option is considered within the same collection data and the same gate fees data, so the comparisons are still valid.
- The research had planned to develop a model from first principles, but the availability of capital and operating costs was too scarce. Therefore it was decided that it was more reliable to use published gate fee data as a reflection of capital and operational costs.

Chapter 7 Results and discussion – Life cycle assessment of municipal waste management

This chapter is the first of three chapters considering the environmental impacts of waste management in isolated communities. In the first part of the chapter, WRATE is used to examine the complete waste stream in the three case study areas, their current practices and theoretical scenarios. In addition, the case of Portsmouth is used to illustrate a non-isolated community, with otherwise similar characteristics to the Isle of Wight, to assess the importance of the geographical barrier. By considering the entire household waste stream in the three study areas plus one non-isolated community the research is providing a baseline situation for the examination of the paper and card waste stream. It is examining the similarities and/or differences between the complete waste stream and just paper and card, to see if the separation of paper for the purposes of the research can be justified and what conclusions can be drawn. The research into the complete waste stream also indentifies some of the key factors to be considered for paper waste in Chapters 9 and 10.

7.1 Isle of Wight input data

For the Isle of Wight, information on waste generation and management routes were taken from "Wastedataflow", a database of statutory returns submitted by all waste collection and disposal authorities (Wastedataflow, 2010). This was also the case for the Shetland Islands. The Norwegian data were collected from the annual reports of the waste management company, NoMil, and also from the national statistics bank (Statistisk Sentralbyrå, 2009). However, these data did not always provide sufficient detail for WRATE (for example the length and average tonnage of collection rounds were not included) so Wastedataflow was supplemented by information obtained by direct contact with the waste management authority on the Isle of Wight (Island Waste, 2009), from the local waste authority annual reports and from a local government website (Isle of Wight Council 2011). The waste system map for the Isle of Wight is representative of the input to WRATE for all the case study areas and is shown in Figure 7.1. Note that this figure and subsequent analysis assume that materials taken to bring recycling banks as part of another journey (shopping, travel to work etc) so no transport element is included.

None of the above sources included a category breakdown of the total waste stream. Although this is an important input to WRATE, it is understandable why local authorities do not obtain such data on a routine basis. Waste surveys are expensive and time consuming, there are some issues over data protection and, for most local authority purposes, national figures are sufficiently accurate. Therefore, the default composition data for England supplied by WRATE was used. In some instances it was necessary to adjust waste amounts to provide 100% coverage for all waste streams; otherwise the data would not be accepted by the LCA model. However, these adjustments were never above the order of 1%, so will have no significance on the results.

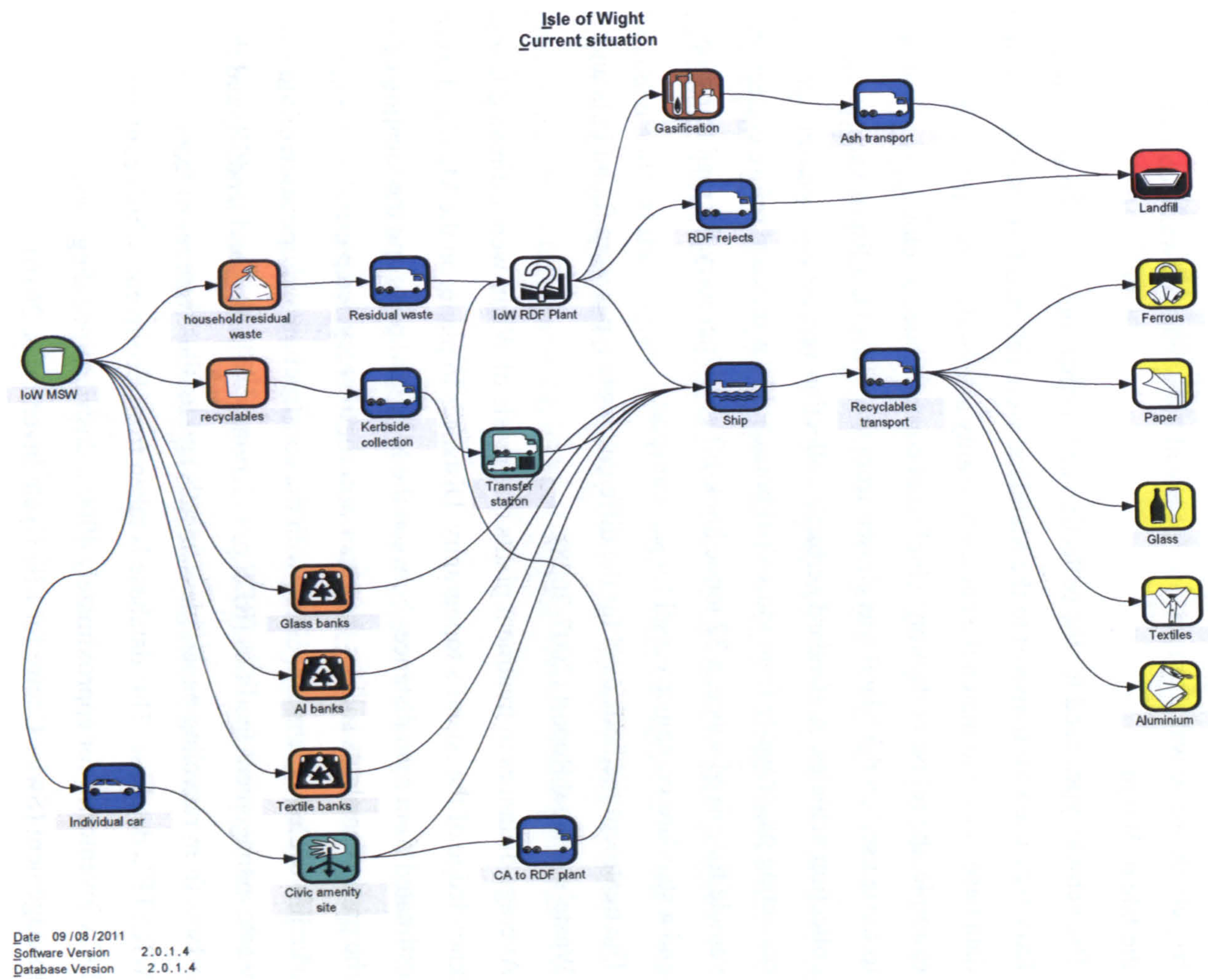

Figure 7.1. WRATE waste system map for the Isle of Wight

For the data input into WRATE for the Isle of Wight, the following sources were used:

- Wastedataflow provided information in 3-monthly periods of the tonnages of waste and recyclables collected and the tonnages of waste and waste types sent to the various treatment options. These 3-monthly periods were totalled to give an annual amount.
- The collection round data, such as the average length of rounds, the average tonnage, the number of collection rounds used and the fuel used, were obtained from North Hampshire collection rounds. This was due to a lack of detailed data from the Isle of Wight collection system and a similarity in the distances involved in the two areas to make the use of North Hampshire data possible.
- The type of waste sacks and bins used both for the mixed waste and for the recyclable waste was from my own personal knowledge of waste collection on the Isle of Wight.
- The vehicle types used for the collection and further transport of waste and the ferry type used for transport to the Mainland were selected from WRATE's own data base, trying to match the choice to reality as closely as possible. For example, the refuse collection vehicle that corresponded as closely as possible to those used on the island was chosen from the WRATE's list of various collection vehicles. A standard kerbside collection vehicle was selected for collecting paper waste from individual households, a standard refuse collection vehicle for mixed waste, a 32 tonne hook-lift container lorry for road transport and a standard container vessel for sea transport.
- The treatment methods used for the different waste types were found in Island Waste's Annual Report (2007-2008).
- Average distances to treatment plants on the Isle of Wight were estimated from knowledge of the island's topography. Distances to plants on the Mainland were estimated from road distances between the Mainland ports and the location of the particular plants such as the paper mill for the recycled paper.
- The life cycle burdens associated with the construction and operation of the waste management facilities (RDF production, gasification and landfill) and the offsets from recycling paper, glass, metals and textiles were taken from WRATE's database. This database is taken from Ecoinvent, which contains LCA inventories for approximately 4000 industries, including waste management (Swiss Centre for Life Cycle Inventories, 2010).

- The electrical power generated by the combustion processes (gasification and landfill gas use) substitutes power generated by the UK average fuels (excluding renewable and nuclear). This comprises 46.6% coal, 49.3% gas and 3.3% oil.

The inputs and composition of Isle of Wight waste to WRATE are summarised in Table 7.1.

7.2 Results for the current Isle of Wight waste system

The effects of the waste management options were grouped into the following six environmental indicators (see glossary for definitions).

1. Climate change,
2. Resource depletion,
3. Acidification,
4. Aquatic Toxicity,
5. Eutrophication,
6. Human Toxicity.

WRATE converts the scale of these effects to 'Euro-persons equivalent' (1 "Euro-person" represents the quantity of that class of pollutant released in a year by an average citizen of the 15 pre-2000 EU member states) so that the different effects can be compared and the overall effect of a particular waste management system can be calculated. However, it must be stressed that the values from each category must not be added and that the magnitude of these values does not signify the order of their importance. For example, in the collection activity, a human toxicity of 30 Euro-persons may be of far greater significance than the resource depletion of 250 Euro-persons.

The results obtained from WRATE are summarised in Table 7.2 and Figure 7.2 below (All numbers in the table are in 'Europersons' per total annual waste managed. Negative effects are in red). Negative effects are, for example, the offsetting of resource use by recycling, such that the environmental burdens of recycling are less than the environmental burdens from products made from virgin materials.

Waste fraction	MSW (t/yr)	Recycling collection (t/yr)	Recycling banks (t/yr)	Civic amenity sites (t/yr)	Total (t/yr)
Newspaper and magazines	4214	2828	0	2169	9211
Mixed paper	4292	0	0	1991	6283
Cardboard	4073	0	0	1784	5857
Plastics	5864	0	0	3020	8884
Textiles	1695	0.04	0	737	2432
Hygiene products (e.g. nappies etc.)	1375	0	0	707	2082
Wood	2115	0	0	1089	3204
Combustible materials (e.g. carpets/furniture)	3578	0	0	1842	5420
Non-combustible (e.g. inert waste)	1563	0	0	803	2366
Green glass	187	102	78	16	383
Brown glass	1496	818	625	167	3106
Clear glass	1360	744	569	131	2804
Jars	340	186	142	62	730
Garden waste	1000	0	0	14000	15 000
Food waste	7156	0	0	2004	9160
Other organic waste	1157	0	0	596	1753
Steel food and drinks cans	2558	0	0	144	2702
Other ferrous	18	0	0	9	27
Aluminium drinks cans	286	0	15	118	419
Foil	153	0	0	79	232
Other non-ferrous	347	0	0	178	525
Fine material	1163	0	0	599	1762
Electrical waste	1310	0	0	674	1984
Hazardous waste	282	0	0	145	427

Table 7.1. The inputs for use in the WRATE LCA analysis. Source: Waste Dataflow (2010) and Island Waste Annual Report 2009.

Waste treatment process	Collection (use of collection sacks)	Transport (from households to disposal)	Intermediate facility	Recycling	Treatment and recovery	Landfill	Total
Climate change	7.01	479	23.8	-1266	-205	357	-604
Resource depletion	22.9	1287	93	-2859	-3632	-459	-5547
Acidification	2.31	322	25	-1065	-69.5	-7.5	-793
Aquatic eco-toxicity	2.86	378	44.5	-3875	-148	154	-3443
Eutrophication	0.59	103	8.81	-214	46.3	117	61.7
Human toxicity	1.4	138	9.7	-3038	59.5	13.7	-2815

Table 7.2. The annual environmental effects of the current waste management system on the Isle of Wight 2010. Europersons/year/tonne of waste managed.

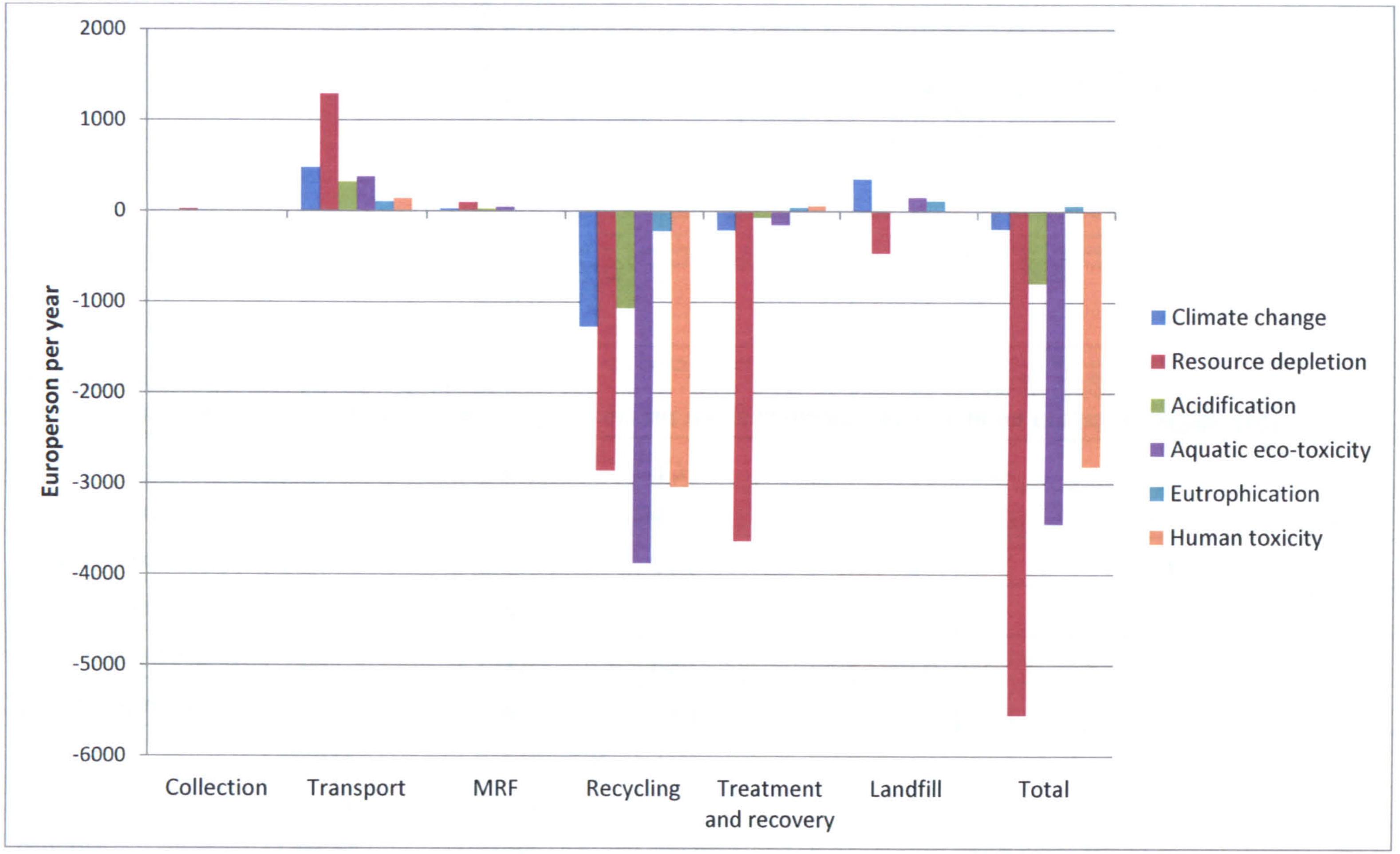

Figure 7.2. The environmental effects of the current waste management system on the Isle of Wight, 2010.

7.3 Discussion of the current Isle of Wight waste system

7.3.1 *Climate change*

From Table 7.2 and Figure 7.2 it can be seen that the current Isle of Wight waste management system has an overall reduction in climate change impacts of approximately 600 europersons per year, with the recycling of metals, paper, glass and textiles providing the greatest benefits. (As mentioned above, 1 "Euro-person" represents the quantity of pollutant released by an average citizen of the 15 pre-2000 EU member states so negative results mean that the emissions released are reduced by the same equivalent). An examination of the WRATE outputs showed that the bulk of this offset was due to the reduction in fossil fuel use when aluminium is manufactured from the reclaimed can-stock rather than from virgin materials. The processes which have an increased effect on climate change are landfill (due to landfill gas emissions) and transport (due to CO_2 emissions from the engine). The environmental effects of transport are described further in Section 8.16.4. It can also be seen that the use of collection sacks and processing of waste at intermediate facilities such as Material Reclamation Facility (MRF) or Refuse Derived Fuel Facility (RDF) have a negligible effect on climate change.

7.3.2 *Resource depletion*

Recycling, treatment and recovery and landfill all contribute to reductions in resource depletion;

- Recycling; due to recycled materials replacing virgin materials and fuel savings,
- treatment and recovery; due to the recovery of energy and its offsetting other fuel sources,
- landfill; due to the offsetting of fuel by burning the landfill gas.

Collection has an increased effect on resource depletion due to the plastic used in the production of sacks, boxes and bins. Transportation has a significant use of resources because of the fuel used in lorry and ferry transport and the MRF use of fuel.

7.3.3 *Acidification*

The overall reduction in acidification within the Isle of Wight waste management system is mainly due to recycling, as there are fewer emissions from recycled products than from products made from virgin materials. Treatment and recovery and landfill also contribute to this reduction due to the offsetting of other fuel sources and a reduction in the emissions of sulphur dioxide to air. Transportation causes a significant increase in acidification due to fuel use, both through the refining of oils and the oxides of nitrogen (NOx) emissions in the vehicle exhausts. Treatment and recovery cause a small increase in acidification due to emissions during the incineration of waste. Collection causes a slight increase due to NOx emissions to air from the manufacture of the one-trip collection sacks.

7.3.4 *Aquatic toxicity*

The Isle of Wight waste management system results in a large reduction in aquatic toxicity due to the recycling of glass, paper, metals and textiles. The release of emissions to water is much reduced when recycled products are compared to products made from virgin materials. Landfill and transport increase the burdens on the aquatic environment, the first from leachate to the water system, the second from acidic and polluting emissions from the use of fuel and from run-off from the road system into water courses. The collection of waste, its intermediate handling and treatment and recovery have no effect on aquatic systems.

7.3.5 *Eutrophication*

This is the only environmental indicator with an overall increase on the environment. All the processes within the waste management system give increased burdens in eutrophication, apart from recycling; the main cause of this is the emission of ammonia to water from landfill sites and NOx emissions from collection and transport vehicles, which are released into the air but then enter soil and water during rain-fall. The treatment and recovery of waste produces phosphates which are released into the water system. Recycling is the only part of the process that results in a reduction in eutrophication which is due to the reduction in NOx and phosphate discharges to air and water, compared to the use of virgin materials.

7.3.6 *Human toxicity*

Again, Table 7.2 shows that recycling causes a large reduction in human toxicity-mainly due to a reduction in atmospheric emissions of poly aromatic hydrocarbons (PAH) whilst the other parts of the system have smaller increases, leading to a large overall reduction. Again the production of plastic products for the collection of waste, the use of fuel in transport and the other parts of the system and the effluents from landfill all produce burdens on human health.

7.4 Shetland, Nordfjord and Portsmouth

As explained in Chapter 4, to assess the Isle of Wight waste management system in comparison to other systems in geographically isolated areas, WRATE was used to model the Shetland Islands (more isolated than the Isle of Wight) and Nordfjord, an isolated community on the west coast of Norway. To compare geographically isolated areas to 'mainland' areas, WRATE was also used to model the management of waste in Portsmouth, the city closest to the Isle of Wight. Portsmouth has a similar sized population to the Isle of Wight and is a similar distance away from the facilities that reprocess the collected materials (but without the geographical barrier of the Solent).

The input of waste data, both for the Shetland Islands and for Portsmouth, were collected from Wastedataflow (2010), from the Orkney and Shetland Area Waste Plan (SEPA, 2003), from Project Integra and from Portsmouth City Council. The data for Nordfjord in Norway were collected from the local waste authority's annual report (NoMil 2006). For Nordfjord, it was assumed that the power displaced from waste combustion would be generated from hydro electric power schemes (the source of over 99% of Norway's power).

7.5 Results

The results for these three areas are summarised in Tables 7.3, 7.4 and 7.5 below. All the data are in 'Europersons' per year and reduced burdens (negative numbers) are in red.

Waste treatment process	Collection (use of collection sacks)	Transportation (collection from households and transport of recyclables)	Intermediate facility	Recycling	Treatment and recovery	Landfill	Total
Climate change	0.8	12	3	-38	-59	55	-26.8
Resource depletion	3	26	10	-110	-615	-74	-759
Acidification	0.25	8.6	2.4	-32	155	-0.2	134
Aquatic eco-toxicity	0.2	10.2	4.1	-44.4	2	21.4	-6.5
Eutrophication	0	3.4	0.8	-5.7	56	27	82
Human toxicity	0.1	3.3	1	-34	8	2	-20

Table 7.3. The annual environmental effects of waste management on the Shetland Islands 2010 (Europersons equivalent per year).

Waste treatment process	Collection (use of collection sacks)	Transportation (from households to disposal)	Intermediate facility	Recycling	Treatment and recovery	Landfill	Total
Climate change	1.86	42.2	0.7	-64.8	-90.5	69.4	-41
Resource depletion	9.6	118	2.6	-204	-338	3.1	-408
Acidification	1.17	37.9	0.7	-62	-68	3.9	-86.7
Aquatic eco-toxicity	1.7	20	1.3	-46.4	-33.3	34	-22.2
Eutrophication	0.2	15.4	0.26	-6.9	-10.7	3.4	1.77
Human toxicity	0.4	7.1	0.3	-51	-12	2.8	-52.3

Table 7.4. The annual environmental effects of waste management in Nordfjord in Norway, 2010 (Europersons equivalent per year).

Waste treatment process	Collection (use of sacks)	Transportation (from households to disposal)	Intermediate facility (MRF)	Recycling	Treatment and recovery	Landfill	Total
Climate change	19.8	156	40.4	-1010	-48.6	124	-718
Resource depletion	83.6	474	126	-2607	-3676	-158	-5756
Acidification	12.1	135	30	-880	60	-0.716	-644
Aquatic eco-toxicity	46.2	111	74	-2242	-161	69.4	-2103
Eutrophication	3.41	50.5	10.8	-132	140	69.7	142
Human toxicity	9.82	39.3	15.9	-1844	-59.1	12.4	-1826

Table 7.5. The annual environmental effects of waste management in Portsmouth, England (Europersons equivalent per year).

7.6 Discussion

To compare the regions to each other, the figures need to be adjusted to a common measurement, in this analysis, per 1000 tonnes of waste managed. The previous figures were for the total annual waste disposed in each area and as the total tonnages were different for the Isle of Wight and the Shetland Islands, for Nordfjord and Portsmouth, the emissions could not be directly compared. The Isle of Wight disposed of 87 638 tonnes per year, the Shetland Islands 11625 tonnes per year, Nordfjord 6889 tonnes and Portsmouth 74718 tonnes per year.

The following tables (7.6 – 7.14) and Figures 7.3 – 7.7 show the results after this adjustment.

7.7 Collection

COLLECTION	Isle of Wight	Shetland	Nordfjord	Portsmouth
Climate change	0.8	0.07	0.27	0.27
Resource depletion	0.26	0.23	1.39	1.12
Acidification	0.02	0.02	0.17	0.16
Aquatic eco-toxicity	0.32	0.02	0.25	0.62
Eutrophication	0.1	0	0.03	0.05
Human toxicity	0.004	0.01	0.06	0.13

Table 7.6. WRATE results for collection in the four areas. Europersons per 1000 tonnes waste.

Table 7.6 is shown graphically in Figure 7.3 below.

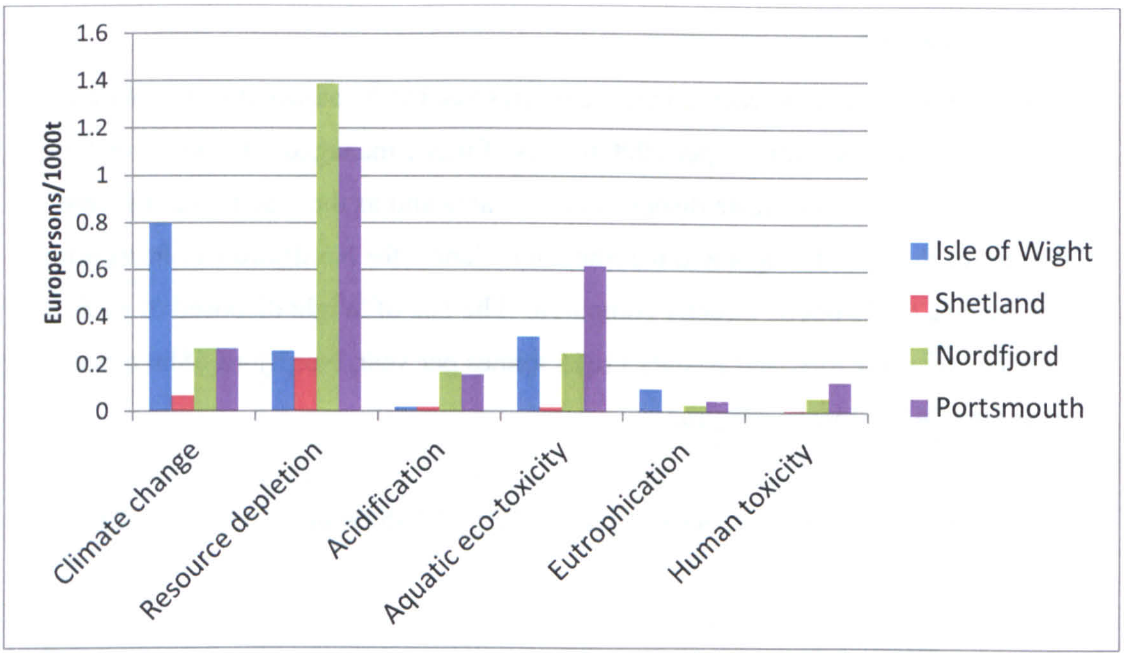

Figure 7.3. The environmental effects of collection in four geographical areas (europersons per 1000 tonnes of waste).

When comparing the environmental effects of the four areas per 1000 tonnes waste disposed it is necessary to consider whether the WRATE modelling is comparing like with like. The MSW collection systems of the Isle of Wight, the Shetland Islands and Portsmouth are similar, with the use of black sacks for mixed waste, collected weekly. However, the Isle of Wight has boxes for recyclables (newspapers, glass) whilst the Shetlands have plastic bags of different colours containing newspapers, glass, cans and plastic bottles. Portsmouth has wheelie-bins which take the dry recyclables; paper and card, plastic bottles, aluminium cans, electric goods and scrap metal. All four areas collect recyclables fortnightly. The collection service in Nordfjord uses wheelie-bins, both for mixed waste and recyclables; the recyclables being organic waste, paper, cardboard and plastic collected once a month. The emissions from the vehicles are not included in the collection data as they are included in the transport system. Although the differences in collection materials will produce different emission levels, these levels will be slight in comparison to the other parts of the system (Table 8.6).

The noticeable differences in the collection systems are the higher climate change effects on the Isle of Wight, resource depletion in Nordfjord and Portsmouth and the higher aquatic eco-toxicity in Portsmouth.

The resource depletion on the Isle of Wight is due to the low average weight of waste per plastic sack (7 kg per sack rather than 11 kg per sack in the Shetland Islands). Higher resource depletion is also a result of the production of wheeled bins for use in Portsmouth and Nordfjord, even with their predicted lifespan of 17 years. The aquatic eco-toxicity levels in Portsmouth and Nordfjord are mainly due to the release of Cobalt, Nickel ions and Vanadium ions to water during the production of the plastic wheelie bins.

To conclude, environmentally speaking, there is no correlation between the degree of isolation of an area and collection impacts, as collection is affected only by the amount of materials collected per container, the collection system and population density.

7.8 Road Transport

Road transport distances vary between the four areas, dependant on the distances to recycling plants, landfill sites and incinerators. The distances are especially significant in Norway and the Shetland Islands, where many materials are transported long distances to larger conurbations. The recyclables from the Isle of Wight and Portsmouth have shorter road distances (Table 7.7).

Recyclable	**Isle of Wight**	**Shetland**	**Nordfjord**	**Portsmouth**
Paper	180	1130	449	180
Cardboard	180	1130	449	180
Aluminium	360	1040	340	360
Glass	25	1100	550	25
Plastics	20	50	1000	20
Compost	20	50	450	13
Mixed waste	25	75	530	20

Table 7.7. Average distances for the road transport of recyclables in the four areas (km).

However, these distances are for varying amounts of recyclables and other waste and this also affects transport emissions. Some areas have local treatment facilities, such as incinerators and landfill sites. The Isle of Wight, the Shetland Islands and Portsmouth all have local incinerators/gasification plants, which reduce the need for transport of mixed residual waste. Nordfjord transports its residual waste to an incinerator in Sweden (530 km) and sends very little waste to landfill, so there are practically no local solutions to waste disposal at all. Table 7.8 shows the percentage waste sent to various treatment options in the four areas.

Waste fraction	Isle of Wight	Shetland	Nordfjord	Portsmouth
Green waste (compost)	0 (0%)	121 (1%)	263 (4%)	2534 (3%)
Recyclables	13 413 (15.3%)	1049 (9%)	1683 (24%)	13 436 (18%)
Incinerator /gasifier waste	38 407 (44%)	7440 (64%)	3075 (45%)	50 436 (68%)
Landfill waste	35 818 (41%)	3136 (27%)	2131 (31%)	10846 (15%)
Total waste	87638	11625	6889	74718

Table 7.8. Waste sent to different treatment options (tonnes per annum). Source: Wastedataflow (2010), NoMil (2006).

It is noticeable from Table 7.8 that the Norwegian community recycles significantly more of its waste than the UK communities. All the communities rely heavily on energy recovery, but have low recycling rates; due to the cost of transport.

All these combined factors give the following environmental effects for transport (Table 7.9 and Figure 7.4).

	Isle of Wight	Shetland	Nordfjord	Portsmouth
Climate change	5.4	0.1	6.13	5.0
Resource depletion	14.6	2.27	17.1	13
Acidification	3.7	0.74	5.5	4.2
Aquatic eco-toxicity	4.3	0.9	2.9	4.3
Eutrophication	1.2	0.3	2.2	1.3
Human toxicity	1.6	0.28	1.0	1.9

Table 7.9. WRATE results for transport in the three areas. Europersons per 1000 tonnes waste.

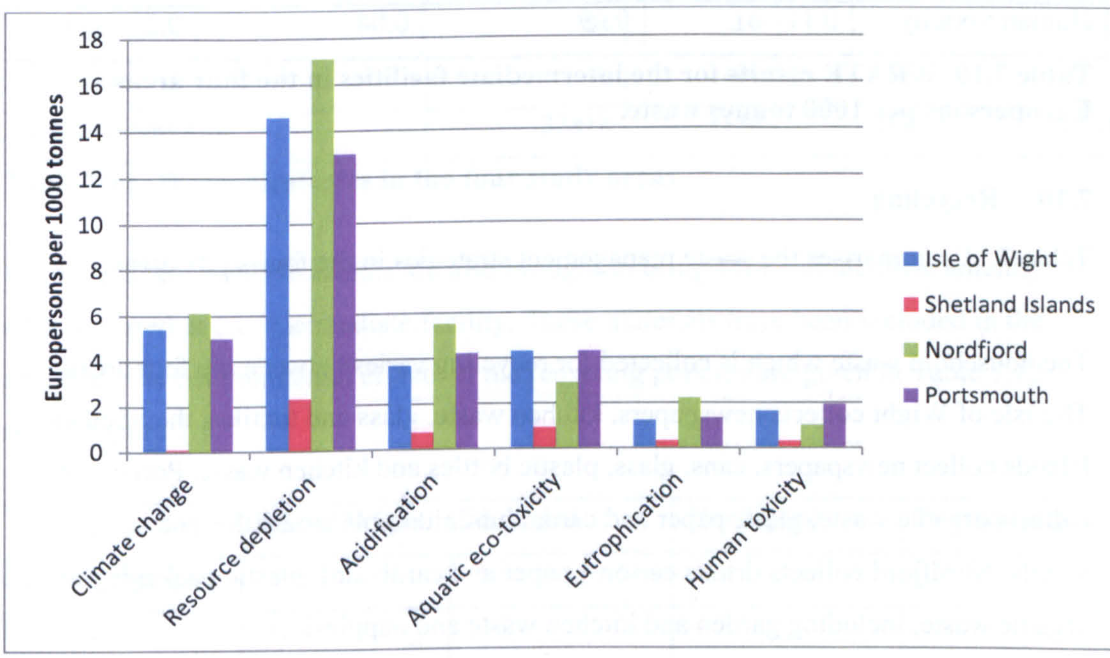

Figure 7.4. The environmental effects of transport in the four areas.

It should be noted that the close proximity of Portsmouth and the Isle of Wight and their similar environmental burdens suggests that the small geographical isolation caused by the Solent is not significant in environmental terms. The larger barrier experienced by the Shetland Islands would have greater environmental significance if the waste was all transported away from the islands, resulting in the necessity for a local solution to waste disposal.

7.9 Materials Recovery Facility

The materials recovery facilities modelled in WRATE are similar for all four areas (Table 7.10).

	Isle of Wight	Shetland	Nordfjord	Portsmouth
Climate change	0.27	0.25	0.1	0.54
Resource depletion	1.05	0.86	0.37	1.7
Acidification	0.28	0.2	0.1	0.4
Aquatic eco-toxicity	0.5	0.36	0.2	1.0
Eutrophication	0.1	0.07	0.04	0.14
Human toxicity	0.11	0.09	0.04	0.2

Table 7.10. WRATE results for the intermediate facilities in the four areas. Europersons per 1000 tonnes waste.

7.10 Recycling

Table 7.11 summarises the waste management strategies in the four study areas.

The household waste which is collected for recycling varies between the four areas. The Isle of Wight collects newspapers, kitchen waste, glass and textiles, the Shetland Islands collect newspapers, cans, glass, plastic bottles and kitchen waste. Portsmouth collects organic waste, glass, paper and card, aluminium, plastic bottles and scrap metals. Nordfjord collects drinks cartons, paper and cardboard, plastic packaging and organic waste, including garden and kitchen waste and nappies.

	Isle of Wight (t)	Shetland (t)	Nordfjord (t)	Portsmouth (t)
Total waste produced	87638	11625	6889	74718
Amount used for energy recovery	38407	7440	3075	50436
Total quantity recycled	13413	1049	1683	13436
Ferrous metal	2289	155	73	1863
Aluminium	1035	10.7	16	623
Glass	6646	733	201	2809
Paper	3358	112	1267	8698
Plastics	0	21	125	581
Textiles	84	16	0	0
Compost	0	121	263	2534
Quantity landfilled	35818	3136	2131	10846

Table 7.11. Waste strategies in the four study areas

In all areas recyclable materials are also brought to bring sites and the civic amenity sites or sorted at the intermediate facility. These materials have been included in the analysis. The environmental effects of the recycling policies are given in Table 7.12 and in Figure 7.5.

	Isle of Wight	Shetland	Nordfjord	Portsmouth
Climate change	-14.4	-3.3	-9.4	-13.5
Resource depletion	-32.6	-9.5	-29.6	-34.9
Acidification	-12.2	-2.7	-9	-11.8
Aquatic eco-toxicity	-44.2	-3.8	-6.7	-30
Eutrophication	-2.4	-0.6	-1	-1.77
Human toxicity	-34.6	-2.9	-7.3	-24.7

Table 7.12. WRATE results for recycling in the four areas. Europersons per 1000 tonnes waste.

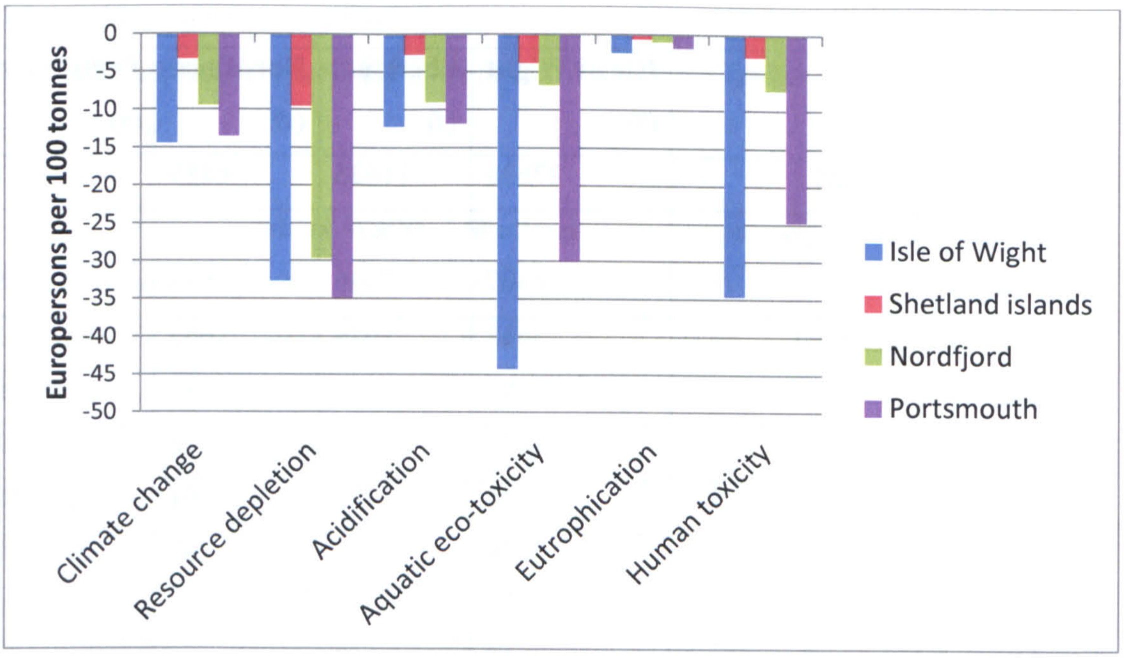

Figure 7.5. The environmental effects of recycling in the four areas.

7.11 Energy recovery

The following table shows the environmental effects of energy recovery in the four areas.

	Isle of Wight	Shetland	Nordfjord	Portsmouth
Climate change	-2.3	-5.1	-13.2	-0.7
Resource depletion	-41.4	-53	-49	-49.2
Acidification	-0.8	13.3	-9.8	0.8
Aquatic eco-toxicity	-1.7	0.2	-4.7	-2.2
Eutrophication	0.5	4.8	-1.6	1.9
Human toxicity	0.7	0.7	-1.7	-0.8

Table 7.13. WRATE results for energy recovery in the three areas. Europersons per 1000 tonnes waste.

From Table 7.13 it can be seen that the saving of resources and climate change reduction through energy recovery is important in all the locations, irrespective of the process used. The greatest climate change benefits are from the waste to heat recovery in Nordfjord. This is due to the fact that the Nordfjord energy station has a thermal efficiency of 80% and displaces the relatively high-carbon oil as the energy source. In contrast, the Shetlands heat station is also efficient, but displaces low-carbon natural gas; thus the displacement has a less beneficial result. The power-only facilities on the

IoW and Portsmouth have a much lower thermal efficiency (around 21%), so are less beneficial in terms of climate change. In terms of resource depletion, the relative efficiencies of power and heat generation do not influence the results, so the values are broadly similar.

Nordfjord performs better for the other emissions due to a combination of high thermal efficiency, the displacement of fuel oil (that contains higher potential pollutant levels than gas) and the presence of a more efficient selective catalytic reduction (SCR) system to reduce NOx emissions compared with the selection non-catalytic reduction (SNCR) NOx control used in the UK facilities.

Inspection of the WRATE emissions inventories showed that the difference in human toxicity values for the Isle of Wight and Portsmouth was found to be due to the atmospheric emissions of poly aromatic hydrocarbons (PAHs) from the Isle of Wight. Further investigation of WRATE failed to determine the origin of these emissions and further work is necessary to determine whether this is an error within WRATE.

7.12 Landfill

The landfill system modelled by WRATE has similar environmental effects for all three areas (Table 7.14). The differences relate to the differing proportions of waste sent to landfill in each location, ranging from 14% in Portsmouth to 41% on the Isle of Wight. Nordfjord is particularly poor in terms of climate change because the landfill gas generated displaced carbon-free hydro electric power rather than the carbon-based UK power mix displaced in the other examples.

	Isle of Wight	Shetland Islands	Nordfjord	Portsmouth
Climate change	4.1	4.8	10	1.6
Resource depletion	-5.2	-6.4	0.44	-2.1
Acidification	-0.1	-0.02	0.6	0
Aquatic eco-toxicity	1.8	1.8	4.9	0.9
Eutrophication	1.3	2.4	0.5	0.9
Human toxicity	0.2	0.2	0.44	0.2

Table 7.14. WRATE and the results for landfill in the four areas. Europersons per 1000 tonnes waste.

7.13 Total environmental affects for the four study areas

Table 7.15 gives the total figures for the environmental variables in the three areas when expressed as Europersons per 1000 tonnes.

	Isle of Wight	Shetland Islands	Nordfjord	Portsmouth
Climate change	-7	-3.2	-6	-6.8
Resource depletion	-87	-66	-59.2	-70
Acidification	-9	11.5	-12.6	-6.2
Aquatic eco-toxicity	-37	-0.55	-3.2	-25
Eutrophication	0.4	6.9	0.26	1.5
Human toxicity	-30	-1.8	-7.6	-24.4

Table 7.15. WRATE results for total environmental effects in the three areas. Europersons per 1000 tonnes waste.

Figure 7.6 shows the environmental indicators in Table 7.15 graphically.

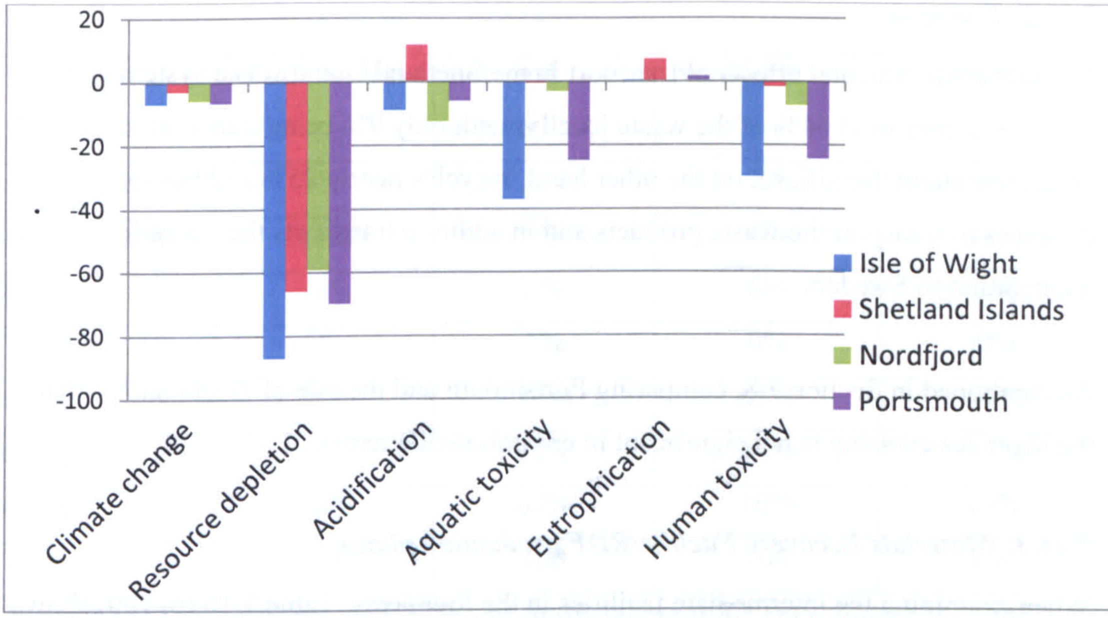

Figure 7.6. Comparison of the total environmental effects of municipal waste management in three regions. Europersons per 1000 tonnes waste.

7.14 Overall discussion of the results for the four study areas and the complete waste stream

7.14.1 Collection

From Table 7.6 and Figure 7.3 (p. 95-6) it can be seen that the Isle of Wight and Shetland have lower levels of resource depletion compared to the other areas. The reduction of resources in the Isle of Wight and Shetland are mainly due to the reduced use of crude oil and natural gas in the production of plastic sacks as compared to recycling boxes and wheelie bins. From this, it could be concluded that it is better to use plastic sacks than wheelie bins for waste collection. However, this has to be weighed against the positive contributions of wheelie bins, which are safer for the disposal operatives and are less likely to be available to foxes and gulls to spill rubbish into the collecting environment. Within the other categories, there are small differences, which are not significant. It must also be remembered that the collection system has very low emission levels in comparison to the other parts of the waste management system.

7.14.2 Transport

The low environmental effects of transport in the Shetland Island waste system is due to the incineration of 64% of the waste locally, with only 9% being transported by road on the mainland. Nordfjord, on the other hand, recycles nearly 25% and has long distances to transport the waste products and in addition transports the waste for incineration to Sweden.

As mentioned in Section 7.8, comparing Portsmouth and the Isle of Wight shows that the short sea crossing is not significant in environmental terms.

7.14.3 Materials Recovery Facility/RDF production plants

When examining the intermediate facilities in the four areas, Table 7.10 (p. 100) shows that it is possible to exclude this part of the system from the assessment as all the areas have similar values and the size of the emissions are not significant in comparison to other parts of the waste management system.

7.14.4 Recycling

To be able to draw any conclusions from the results of WRATE and recycling it is necessary to consider the different amounts of waste products being recycled in the four areas. This is because some recycled products, such as aluminium, have much greater environmental benefits than others (e.g. glass). Table 7.17 and Figure 7.7 (below) give this information.

Although the figures in Table 7.17 seem small, when they are multiplied by the percentages sent for recycling they become more significant and the differences become more pronounced. Thus it is important to consider the composition of the material sent for recycling in the different areas (Table 7.16).

	Isle of Wight	Shetland Islands	Nordfjord	Portsmouth
Aluminium	8%	1%	1%	4%
Ferrous metals	17%	13%	4%	11%
Plastic	0%	2%	6%	3%
Textiles	1%	1%	0%	0%
Paper	25%	10%	65%	51%
Compost	0%	10%	14%	15%
Glass	50%	63%	10%	16%
Total	100	100	100	100

Table 7.16. The percentage of different materials sent for recycling in the four study areas.

Table 7.12 is repeated below, to be able to use in conjunction with the information in Table 7.16 and 7.17.

Environmental indicator	Aluminium cans	Ferrous metal	Plastic bottles	Textiles	Paper	Compost	Glass
Climate change	-0.83	-0.126	-0.0915	-0.0338	-0.0232	-0.00322	-0.00195
Resource depletion	-1.56	-0.394	-0.635	-0.887	-0.0649	-0.00079	-0.00778
Acidification	-0.706	-0.0817	-0.672	-0.0442	-0.0292	-0.00037	-0.00171
Aquatic eco-toxicity	-3.7	-0.0326	-0.00262	-0.00537	0.0125	0.000725	-0.00123
Eutrophication	-0.137	-0.0176	-0.00183	-0.0128	-0.00499	0.00616	-0.00061
Human toxicity	-2.86	-0.0245	-0.000617	-0.00307	-0.00378	0.00367	-0.00039

Table 7.17. The environmental impact of recycling different materials (Europersons equivalent per tonne).

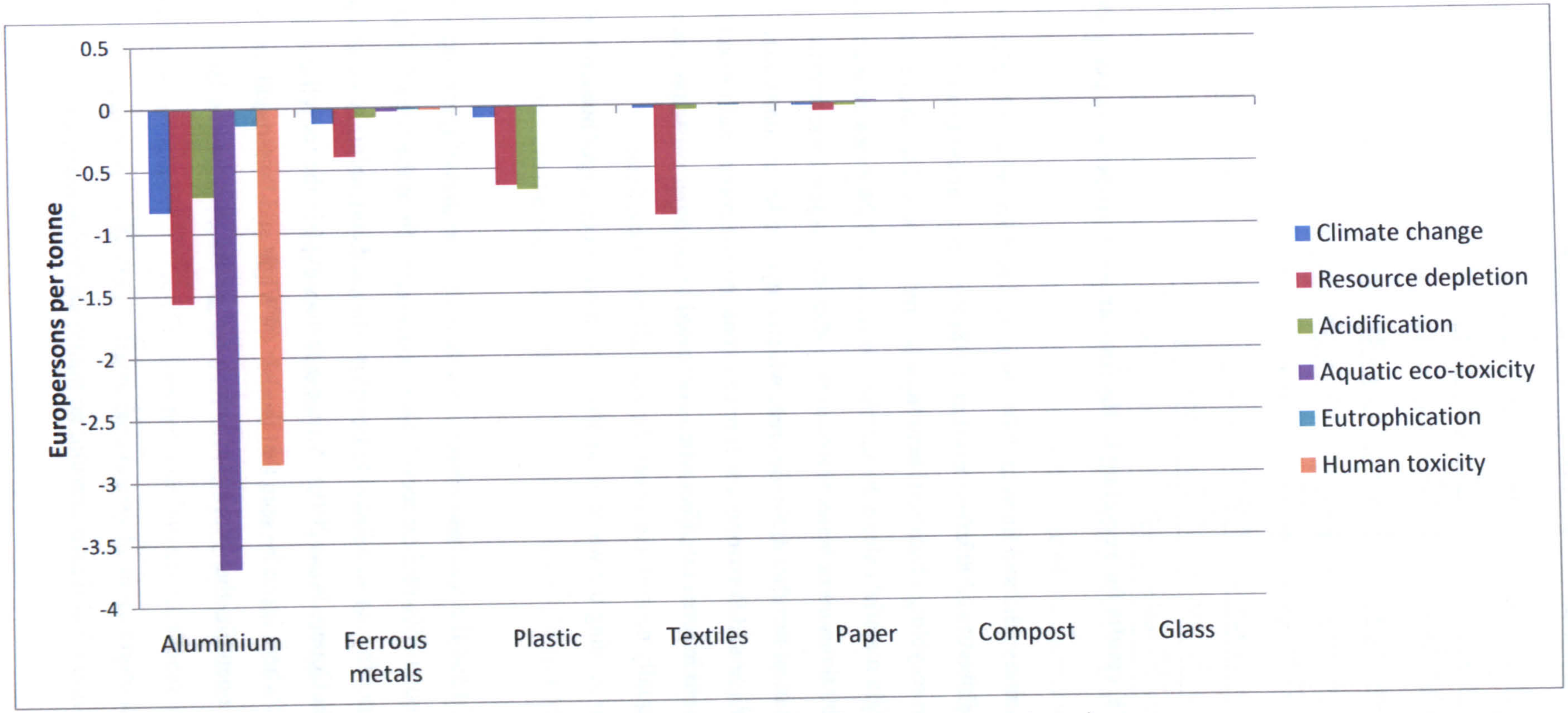

Figure 7.7. The environmental impact of recycling different materials (Europersons per tonne).

RECYCLING	Isle of Wight	Shetland	Nordfjord	Portsmouth
Climate change	-14.4	-3.3	-9.4	-13.5
Resource depletion	-32.6	-9.5	-29.6	-34.9
Acidification	-12.2	-2.7	-9	-11.8
Aquatic eco-toxicity	-44.2	-3.8	-6.7	-30
Eutrophication	-2.4	-0.6	-1	-1.77
Human toxicity	-34.6	-2.9	-7.3	-24.7

Table 7.12. WRATE results for recycling in the four areas. Europersons per 1000 tonnes waste.

From the literature survey (Bai and Sutanto 2001; Berglund and Söderholm 2003; Grant et al. 2001; Dahlbo et al 2005; Merrild et al 2008) there is clear evidence to support the view that recycling of waste is beneficial in environmental terms, i.e. it is better than using virgin materials alone. In addition, from Table 8.24 it can be seen that aluminium is 10-1000 times more beneficial than the other dry recyclables, ferrous metal being the next most beneficial. So the areas which recycle a lot of aluminium such as the Isle of Wight and Portsmouth will have a reduced environmental impact. Glass has next to no environmental effect when compared to the other waste products and composting is equally neutral. However, they are all more beneficial environmentally than sending the waste to landfill, which produces larger burdens on the environment.

Both the Isle of Wight and the Shetland Islands recycle high quantities of glass and all the areas compost around 15% of their recyclable material apart from the Isle of Wight, where their composting facility was found to be below standard and had to be closed in 2010 (Island of Wight County Press 2010). All these factors explain the recycling effects in Table 7.12, where it can be seen that the Isle of Wight and Portsmouth have greater environmental benefits than Nordfjord, which are greater than the Shetland Islands.

7.14.5 Energy recovery

From Table 7.13 (p.102) it can be seen that the saving of resources through energy recovery is important in all the areas, irrespective of the kind of treatment used. From Table 7.21 (discussed further on p.121) it can be seen that the greatest climate change benefits are from the recovery of heat (rather than power) in Nordfjord. Most electricity (90%) in Norway is from hydro-electric processes which are carbon neutral and cause little pollution. The heat produced by the incinerator is used by the few industrial processes which use fossil fuels for space or process heating. The incinerator in Norway has an energy conversion efficiency of 80% and thus gives even greater savings than the heat substituted in the Shetland Islands. Also from the table, it is noticeable that acidification, aquatic eco-toxicity, eutrophication and human toxicity are all less when electricity is produced in Portsmouth as compared to heat in the Shetland Islands. Again, this could be due to the age of the incinerator on the Shetland Islands or due to the greater efficiency of producing electricity rather than heat from the heat to energy process. However, the incineration process in Nordfjord produces heat and has the least environmental burdens of all four areas, so this would tend to confirm that it is the age of the Lerwick plant which is the cause of the inefficiencies. The gasification plant on the Isle of Wight is no better environmentally than the incinerator in Portsmouth for the complete waste stream. As the technology should be more efficient in the production of electricity than the normal incinerators, it could be the content of the waste stream and the amounts being processed that need to be examined.

7.14.6 Landfill

The environmental effects of landfill as shown in Table 7.14 (p.104) are similar for all areas.

However, it can be seen that the environmental burdens of sending waste to landfill are directly proportional to the amounts disposed of. Nordfjord has the highest environmental burdens due to the fact that the gas collected from landfill sites is used to displace hydropower, which is a neutral source of power as regards the environmental indicators examined by WRATE. The results also show that the effects of landfill are the same in geographically isolated areas as they are in 'mainland' areas. It is worth noting at this stage that WRATE does not take into account local effects, such as noise, smell, impacts on biodiversity. These factors may be more important for isolated communities, especially those reliant on tourism, than it is for non-isolated areas.

7.14.7 The total environmental effects of the current waste systems in the four areas

From Table 7.15 and Figure 7.6 (p.104-5) it can be seen that there are significant differences in aquatic eco-toxicity and human toxicity, with the environmental effects being lower in Portsmouth and the Isle of Wight for both environmental indicators than in Nordfjord and on the Shetland Islands. The Shetland Islands have higher levels for both acidification and eutrophication in comparison to the other three areas. From the previous discussion of the various parts of the waste management systems in the areas, these results are mainly due to the differences in the recycling and energy recovery systems and, to a lesser extent, the road transport distances for each area.

7.15 Conclusions from the comparison of complete waste streams

The environmental effects of waste management in each of the four areas, which is given as totals in Table 7.15 can be broken down into the system components and is given in Table 7.18.

System component	**Environmental indicator**	**Isle of Wight**	**Shetland Islands**	**Nordfjord**	**Portsmouth**
Collection	Climate change	0.03	0.07	0.27	0.27
	Resource depletion	1.9	0.23	1.39	1.12
	Acidification	0	0.02	0.17	0.16
	Aquatic eco-toxicity	0	0.02	0.25	0.62
	Eutrophication	0.1	0	0.03	0.05
	Human toxicity	0.3	0.01	0.06	0.13
Transport	Climate change	5.1	0.1	6.13	5.0
	Resource depletion	14	2.27	17.1	13
	Acidification	4.3	0.74	5.5	4.2
	Aquatic eco-toxicity	4.6	0.9	2.9	4.3
	Eutrophication	1.3	0.3	2.2	1.3
	Human toxicity	2	0.28	1.0	1.9
MRF	Climate change	0.03	0.25	0.1	0.54
	Resource depletion	0	0.86	0.37	1.7
	Acidification	0.03	0.2	0.1	0.4
	Aquatic eco-toxicity	0	0.36	0.2	1.0
	Eutrophication	0.1	0.07	0.04	0.14
	Human toxicity	0.3	0.09	0.04	0.2

Recycling	Climate change	-14	-3.3	-9.4	-13.5
	Resource depletion	-33	-9.5	-29.6	-34.9
	Acidification	-12	-2.7	-9	-11.8
	Aquatic eco-toxicity	-43	-3.8	-6.7	-30
	Eutrophication	-2.6	-0.6	-1	-1.77
	Human toxicity	-34.2	-2.9	-7.3	-24.7
Energy recovery	Climate change	-2.8	-5.1	-13.2	-0.7
	Resource depletion	-65	-53	-49	-49.2
	Acidification	-1.4	13.3	-9.8	0.8
	Aquatic eco-toxicity	0	0.2	-4.7	-2.2
	Eutrophication	0.28	4.8	-1.6	1.9
	Human toxicity	0.4	0.7	-1.7	-0.8
Landfill	Climate change	4.3	4.8	10	1.6
	Resource depletion	-5.7	-6.4	0.44	-2.1
	Acidification	-0.3	-0.02	0.6	0
	Aquatic eco-toxicity	1.14	1.8	4.9	0.9
	Eutrophication	1.3	2.4	0.5	0.9
	Human toxicity	0.2	0.2	0.44	0.2
Total	Climate change	-7	-3.2	-6	-6.8
	Resource depletion	-87	-66	-59.2	-70
	Acidification	-9	11.5	-12.6	-6.2
	Aquatic eco-toxicity	-37	-0.55	-3.2	-25
	Eutrophication	0.4	6.9	0.26	1.5
	Human toxicity	-30	-1.8	-7.6	-24.4

Table 7.18. A breakdown of the environmental effects of waste management in the four areas.

From the table it is possible to assess where the differences in the environmental effects in the four areas come from:

- The reduced benefits on climate change from the Shetland Islands waste system are due to the recycling system, which, as mentioned above, has low levels of aluminium recycling.
- For most of the measured environmental indicators, the Shetland Islands have smaller reductions in burdens than the other two areas. The incinerator at Lerwick, on the Shetland Islands, was originally built in 1953 and added to in 1996. The incinerator was renewed in January 2000 (Defra 2010). The greater burdens from acidification, eutrophication and toxicity relate to the atmospheric

emissions where the pollution control equipment is less advanced than that in the other facilities.

- Portsmouth and the Isle of Wight have reduced aquatic eco-toxicity due to their recycling policies.
- It can be seen that there is no significant difference in the environmental effects of waste management in an isolated community (the Isle of Wight) compared to a mainland community (Portsmouth). There are greater differences shown between the three isolated communities than between an isolated and a mainland community.
- For all three areas, out of all the waste management system components measured, transport is the cause of the highest burdens. This is especially the case on the Isle of Wight, Portsmouth and Nordfjord, where road transport distances are high;
- Recycling and treatment and recovery give the high reductions in most categories, although the system in the Shetlands gives increased acidification, aquatic eco-toxicity, eutrophication and human toxicity. The incinerating system in Lerwick emits high levels of nitrogen oxides to air, which is the main cause of eutrophication in this case and high levels of sulphur oxides to air causing acidification. The gasification plant on the Isle of Wight has a reduced effect on acidification and the energy from waste plant in Norway has a reduced effect on both eutrophication and acidification;
- Recycling, treatment and recovery and landfill all have reduced resource depletion. However, the benefits of recycling are due to a wide range of recyclables and it is clear that some recyclables, such as aluminium, are more beneficial than others.
- Eutrophication is caused by transport and landfill and, to a lesser extent, collection, treatment and recovery in both the UK sites. In Nordfjord, transport and landfill cause eutrophication.

7.16 Different waste scenarios within each waste management area

To examine how the current scenarios in the three areas compare with other possible waste management strategies, WRATE was used to model a number of theoretical scenarios with the current methods for waste management in the areas. Whilst it is recognised that none of these scenarios would ever be implemented, they provide useful comparisons.

7.16.1 *Isle of Wight*

In this case, three theoretical scenarios were examined:

- Sending all the waste to landfill,
- Sending all the waste to incineration,
- The current scenario, but incineration with energy recovery rather than gasification.

The results for these three scenarios are shown in Figure 7.8 below. This figure shows the obviously detrimental effects of sending all the waste to landfill as expected and all the indicators show higher environmental burdens, apart from resource depletion due to the recovery of landfill gas. Comparing the two incineration-based options of burning all the waste and incineration with current recycling shows only small differences. Incinerating all the waste is slightly better in most impact categories whilst incineration with limited recycling is better in terms of acidification and eutrophication.

From the WRATE data it is shown that with the gasification of waste:

- Acidification is significantly decreased by reduced emissions of nitrogen oxides and sulphur dioxide to air.
- Aquatic eco-toxicity is significantly decreased by reduced emissions of vanadium to water,
- Human toxicity is significantly decreased by reduced emissions of polycyclic aromatic hydrocarbon (PAH) emissions to air.

These findings are summarised in Table 7.19 where the units are Europersons per year.

Figure 7.8. Comparison of the environmental effects of different waste management scenarios on the Isle of Wight.

Environmental indicator		Current scenario	Landfill	Incineration	Current + incineration
Acidification	Total	-837	303	-88.9	-169
	From sulphur dioxide	-817	43.1	-364	-388
	From NOx	-212	155	274	240
Aquatic eco-toxicity	total	-3281	473	-509	-379
	From vanadium	-3255	54.9	-526	-459
Human toxicity	total	-2825	123	-476	-422
	From PAH	-2600	26.5	-445	-393

Table 7.19. The emissions responsible for the differences in environmental effects of waste management systems.

7.16.2 Shetland

Four theoretical scenarios were compared with the current scenario:

- All waste being incinerated on the island with no recycling,
- All waste being incinerated, but generating power rather than heat,
- The current scenario, but with no recycling, all recyclables being sent to landfill,
- All waste to landfill on the islands.

The results are shown in Table 7.20 and Figure 7.9. For comparison, the current situation is shown, both excluding and including the transport of recyclables to the mainland (150 km by sea and 500 km by road). All numbers are in Europersons per annum and negative figures in the table are in red.

Environmental indicator	Current scenario	Current + transport	Incineration + heat	Incineration + power	Current with no recycling	All waste to landfill
Climate change	-54.8	-40.9	-110	-40.3	-6.92	215
Resource depletion	-871	-816	-1000	-781	-760	-219
Acidification	108	125	216	26.3	142	8.63
Aquatic eco-toxicity	-12.7	-2.58	52.8	23.5	34.1	23.1
Eutrophication	74.4	80.7	82.5	37.7	85.2	102
Human toxicity	-19.2	-15.6	27.3	-2.26	15.8	1.69

Table 7.20. The environmental effects of waste management in the Shetland Isles

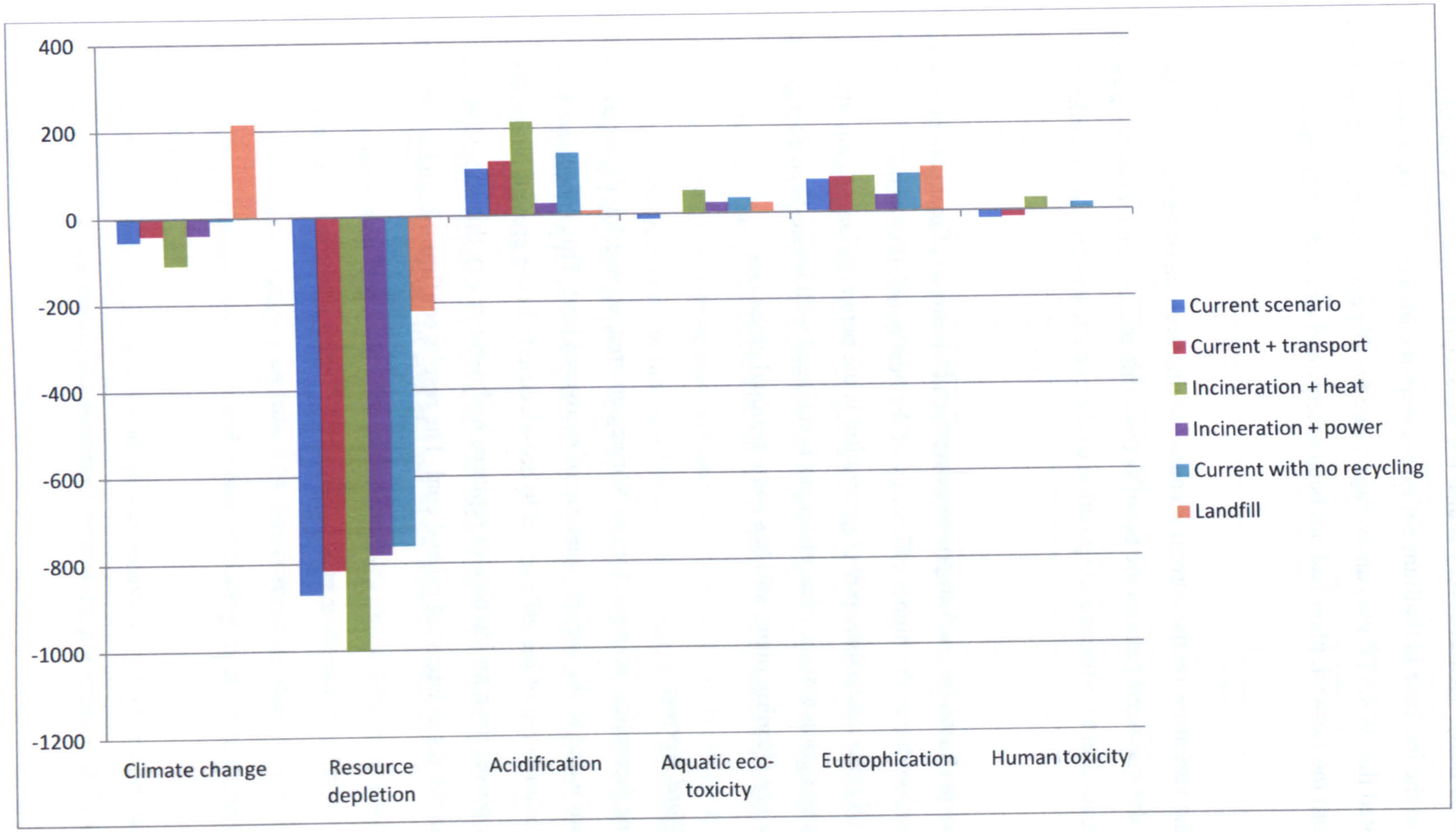

Figure 7.9. Comparison of the environmental effects of different waste management scenarios in the Shetland Islands.

From Figure 7.9 and Table 7.20 it can be seen that landfill presents the least beneficial option for all impact categories. When it comes to the most beneficial scenario, there is no clear cut best option. Heat recovery performs best for climate change and resource depletion, but worst in acidification (as this process replaces acid gas-free gas fired heat with waste-fired heat). Heat recovery is also the worst option in terms of human toxicity due to the increase in thallium emissions from the incinerator. However, it should be noted that WRATE uses an average value for this emission because thallium emissions from the Lerwick plant had not been determined when WRATE was compiled.

Comparing the variations on the current scenario, taking account of transport of the recyclates to the mainland reduces the benefits from this scenario, but does not provide a sufficient reduction to influence the position of the current scenario in the order of preference.

Heat recovery performs better than power generation in terms of climate change and resource depletion due to the higher efficiency of the heat generation process. However, in all other categories, power generation is the better option. Again, this is because the heat option assumes that clean gas is replaced with waste-fired energy that, in spite of the gas cleaning plant, still has some residual emissions.

7.16.3 Nordfjord, Norway

There was one theoretical scenario for the Norwegian area; comparing the recovery of electricity from waste to the present scenario of recovered heat. This is because this will give a measurement of the efficacy of hydro-electricity in the present Norwegian system. If the power from an incinerator replaces hydro-electricity this should be less beneficial than the replacement of oil and coal. The results confirm this and are shown in Table 7.21.

Environmental indicator	Current scenario	Current scenario with power recovery
Climate change	-41	120
Resource depletion	-408	-54.2
Acidification	-86.7	-8.96
Aquatic eco-toxicity	-22.2	18.1
Eutrophication	1.77	17.5
Human toxicity	-52.3	-37.2

Table 7.21. The comparison of heat recovery with power recovery in Nordfjord, Norway. Europersons per year.

The table shows that heat recovery gives significantly fewer environmental burdens than power recovery. From a breakdown of the WRATE data, the reasons for this are:

- Climate change is affected by the emissions of CO_2, which are 64.3 Europersons for power recovery and -91.4 Europersons for heat recovery due to the greater reduction in the use of fossil fuels when heat is recovered. The fact that the recovery of power increases climate change impacts is due to the release of fossil CO_2 to air during the recovery process and the displacement of CO_2-free hydropower.
- Resource depletion is reduced with heat recovery by less use of oil and a lesser reduction in the use of coal and gas in the recovery processes,
- Acidification is greater with power recovery due to higher emissions of NOx and SO_2 to air during the process than occurs with heat recovery,
- Aquatic eco-toxicity is increased by power recovery due to small increases in a variety of emissions to soil and water, including metals like copper and vanadium,
- Eutrophication is increased with power recovery by higher nitrogen oxide emissions to air during the treatment processes, phosphates and COD to water,

- Human toxicity, like aquatic toxicity is affected by the increase in trace elements and metals released to air soil and water.

Thus, it is clear that the recovery of heat rather than power in Nordfjord is the better environmental option.

7.16.4 Transport impacts

Transport impacts are generally considered to be an important part of any waste management system, especially in geographically isolated areas. In this test, WRATE was used to assess the effect of varying the sea and land transport distances in the case of Shetland. The results are shown in Table 7.22.

		Sea 150 km					**Sea 300 km**
Impact	**No transport**	**Road 100 km**	**Road 200 km**	**Road 300 km**	**Road 400 km**	**Road 500 km**	**Road 100 km**
Climate change	-26.8	-22.9	-19	-15.2	-11.4	-7.54	-22.8
Resource depletion	-759	-748	-738	-727	-716	-706	-748
Acidification	134	137	140	144	147	150	137
Aquatic eco-toxicity	-6.49	-4.48	-2.5	-0.514	1.47	3.45	-4.46
Eutrophication	81.9	83.2	84.4	85.6	86.8	88.1	83.2
Human toxicity	-20.3	-19.6	-18.9	-18.2	-17.4	-16.7	-19.6

Table 7.22. Impact of transport emissions (Euro persons equivalent).

Table 7.22 shows that the effects of sea transport are small. The transport by sea of 150km (then by road 100km) has almost the same environmental burdens as transport by sea for 300km (then transport by road 100km). Whilst this finding may appear to be counter-intuitive, sea transport is highly energy efficient. Furthermore, these findings are supported by WRAP (2008) research that demonstrated there are environmental benefits of transporting recyclable materials (paper and plastic bottles) from the UK to China for processing.

The effects of road transport, however, are shown to be significantly increased with distance. The percentage increases in the environmental burdens over distance are shown in Figure 7.10.

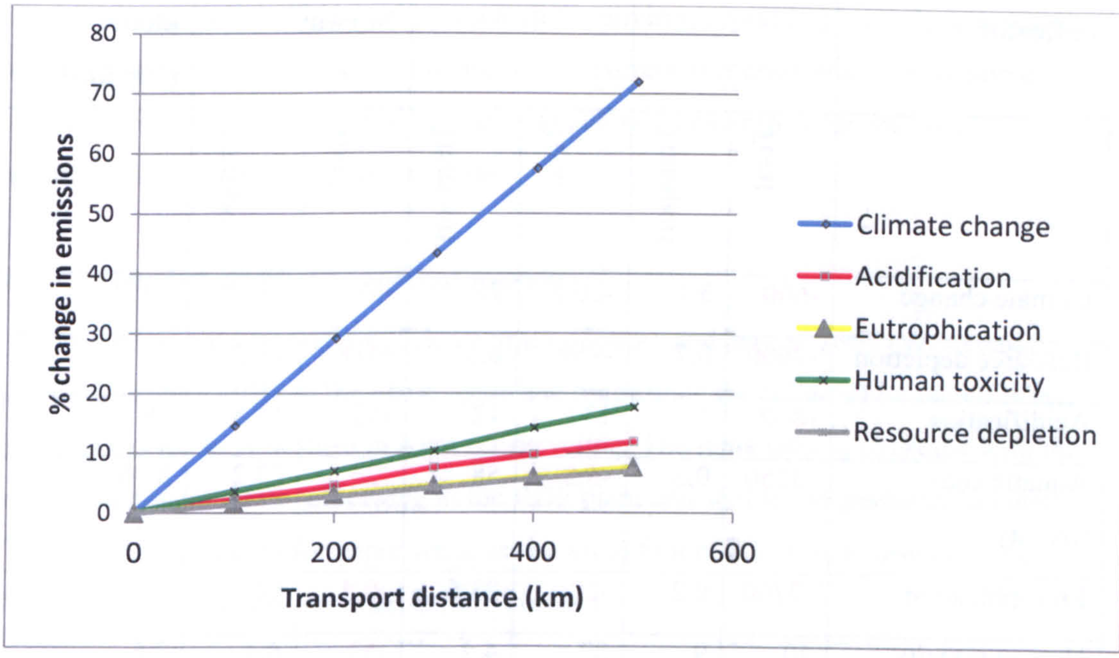

Figure 7.10. % change in environmental burdens produced by transport over distance.

In figure 7.10, the changes in aquatic eco-toxicity have been omitted because the percentage increase was 30.9% at 100 km and rose to 153% when transport was 500 km, which made the other environmental indicators hard to see on the graph. If 5% is taken as the limit for a significant change, then all the environmental burdens are significantly increased by road transport; climate change and aquatic eco-toxicity by 100 km transport distance and the other indicators by longer distances.

Table 7.23 shows 500 km road transport as a percentage of the total environmental burdens in the different areas (Column 1 for each area shows the total environmental effects, column 2, the effect of transport). From the table it can be seen that the influence of long distance transport on environmental burdens differs from one geographically isolated area to another. The Isle of Wight, for example, has high, negative environmental burdens for all environmental indicators, apart from human toxicity. These indicators are not significantly affected by the transport burdens. The Norwegian data show that the burdens are significantly increased by long-distance transport (apart from human toxicity). For the Shetland Islands, all the environmental burdens, apart from climate change and human toxicity, are affected by long-distance transport.

Environmental indicator	Isle of Wight		Shetland		Nordfjord, Norway		Transport alone (500 km)
	Total	Transport	Total	Transport	Total	Transport	
Climate change	-600	3.1	-26.8	2.7	-43	31	19.26
Resource depletion	-7600	0.7	-759	6.5	-418	11.25	53
Acidification	-800	2	134	12	-92	14.8	16
Aquatic eco-toxicity	-3250	0.3	-6.5	58	-24	27.2	8.96
Eutrophication	-2700	0.2	-20	23.6	-0.4	94	6.2
Human toxicity	40	9	82	4.2	-53	6.4	3.6

Table 7.23. The environmental effects of transport in the three areas

7.16.5 Summary

From this chapter, the following key points can be made:

- The source of the power which is being replaced from incineration and energy recovery or gasification is important to the degree of environmental benefits from these processes,
- The use of incineration with heat recovery or incineration with power recovery needs to be assessed in relation to the fuel sources being displaced,
- Road transport distances are important to the overall environmental effects of a waste management option. The longer distances make some options less environmentally beneficial.
- Sea transport within the distances studied are not significant environmentally,
- Comparing Portsmouth and the Isle of Wight shows that, environmentally speaking, the isolation caused by the Solent in unimportant.
- Landfill is always the worst environmental option and any non-landfill waste management system reduces the environmental impact.

Chapter 8 Results and discussion – Life cycle assessment of paper waste management

8.1 Introduction

In this chapter WRATE is used to research the environmental impacts of paper waste management in the three case study areas. The current scenarios practiced within each area are compared to theoretical scenarios to assess whether they are the most environmentally beneficial for the areas.

8.2 The Isle of Wight - current scenario

The Isle of Wight disposed of 25,351 tonnes of paper and card in 2009 (Wastedataflow, 2010). Currently, 70% of the newspapers and magazines are collected by Island Waste and transported to Aylesford in Kent for recycling. The remainder is collected with the mixed municipal waste, processed in the RDF plant and sent to the gasification plant. The waste system map for paper waste is shown in Figure 8.1 and the results of the WRATE modelling are summarised in Table 8.1.

From Table 8.1, it can be seen that the current system of paper waste management on the Isle of Wight has an overall environmental benefit for all six environmental indicators measured. Overall, it is the collection (provision of bins, sacks etc.) and transport (household collections and transport to the recycling/recovery facilities) that give increased burdens, whilst recycling and gasification are responsible for reduced environmental burdens. The operation of the MRF and landfill of rejects from the RDF production process account for a small increase in the environmental burdens. In this analysis, the RDF plant and gasification process are both included under the heading "gasification". If treated separately, the RDF plant would also show a small increase in environmental burdens in all categories.

The increased climate change values for the collection and transport services are mainly due to emissions of CO_2 to air from the fuel used by the vehicles. The reduction in climate change values for recycling and gasification are mainly due to reduced CO_2 and reduced methane emissions to air from reduced fossil fuel use; for recycling this is a reduction in comparison to the production of paper and card from virgin materials (recycling one tonne of paper reduces CO_2-equivalent emissions by 376 kg) and for gasification the energy produced from the process is a substitute for fossil fuels.

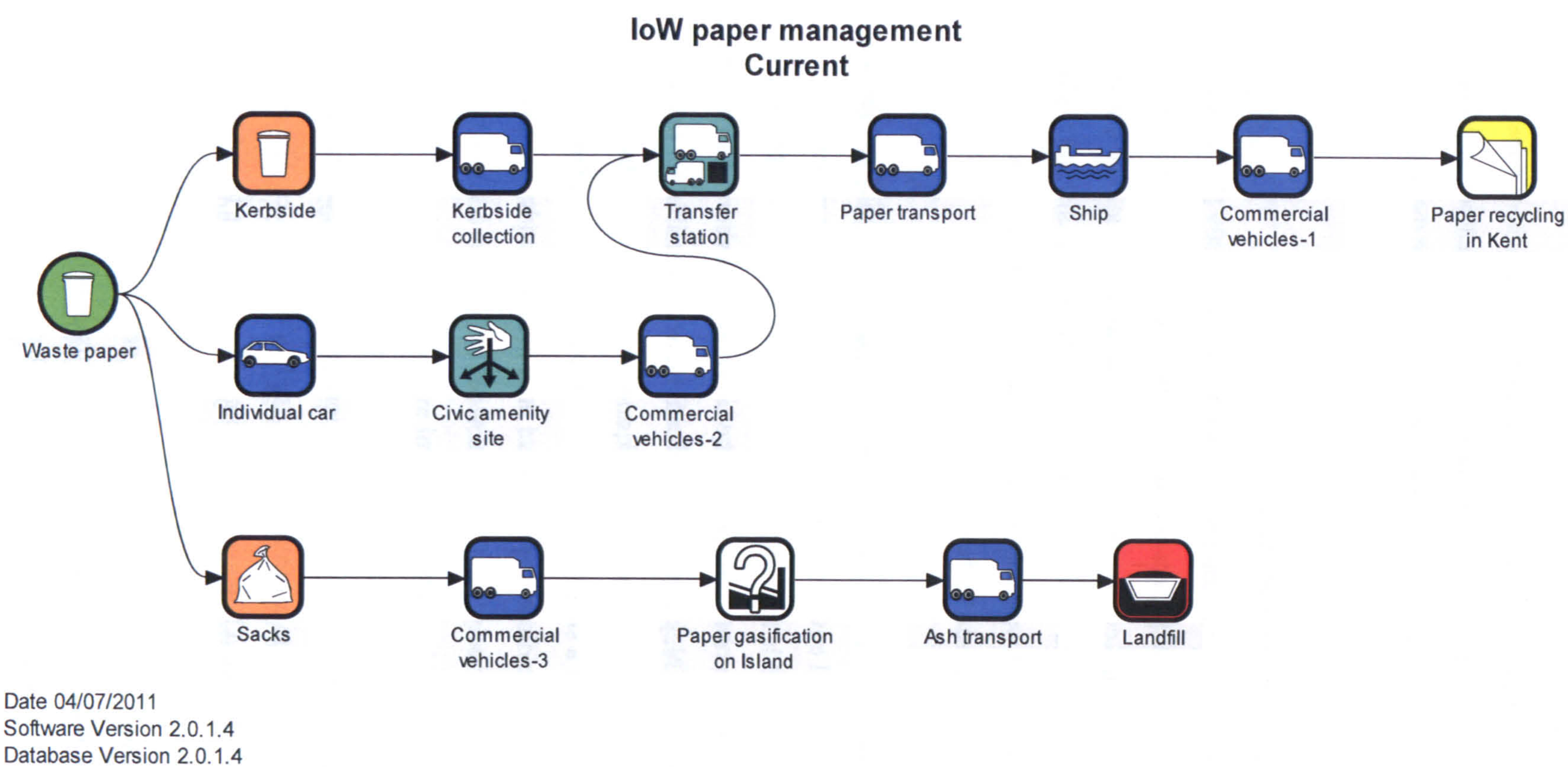

Figure 8.1. The waste system map for paper waste on the Isle of Wight.

Environmental indicator	Collection	Transport	MRF	Recycling	Gasification	Landfill	Total
Climate change	9.26	27.4	0.7	-54.2	-594	0.5	-610
Resource depletion	52.5	76.5	2.38	-152	-1573	3.8	-1590
Acidification	5.13	23.1	0.6	-68.3	-63.7	0.8	-102
Aqua eco-toxicity	0.9	16.2	1	29	-86.8	38.9	-0.7
Eutrophication	0.9	9	0.2	-11.7	-6	1	-6.4
Human toxicity	0.4	5.8	0.2	-8.9	-38	6.1	-34.6

Table 8.1. The environmental effects of current paper waste management on the Isle of Wight (Europersons equivalent).

With resource depletion, the use of crude oil for the vehicles fuel gives most of the increased values. The reduced values for recycling are due to a reduction in the use of coal and oil; for gasification due to the substitution of energy for coal, gas and oil.

Acidification from collection and transport is caused by emissions of NOx and SO_2 to air from the vehicles. Recycling and gasification have reduced acidification from the reduced emissions of these two compounds.

Aquatic eco-toxicity is mainly increased for transport, recycling and landfill. Transport causes the release of nickel ions, barite and vanadium ions to water, recycling the release of copper ions to water and landfill releases copper, barium, vanadium, nickel and molybdenum to water. Gasification and recycling reduce the emissions of polycyclic aromatic hydrocarbons (PAH) to air, hydrogen to air and gasification reduces emissions of barite to water.

Eutrophication is increased for transport due to emissions of NOx to air and COD to water. Eutrophication is reduced for recycling and gasification due to a reduction in the emissions of NOx to air and COD to water.

Human toxicity is increased for transport due to the release of a number of trace elements such as arsenic and chromium to air. Landfill increases human toxicity due to the release of molybdenum and other elements to water through leachate leaks.

8.3 Theoretical scenarios for paper waste management on the Isle of Wight

Four different theoretical scenarios were examined using WRATE, with the aim of comparing the current paper waste management practices with other possible options:

1. The current scenario;
2. All paper to landfill;
3. All paper to gasification;
4. All recoverable paper to recycling;
5. All recoverable paper to composting.

In the cases of recycling and composting, the non-recoverable paper is sent to the gasification plant as at present. The results are summarised in Table 8.2 and Figure 8.2 below. It is recognised that paper can only be composted when mixed with a suitable high nitrogen material such as garden waste. It is assumed that such a waste would be available, but this scenario only considered the paper-related impacts.

All figures are in 'Europersons' per year. Negative effects are in red.

Environmental indicator	**Current**	**All paper to landfill**	**All paper to gasification**	**All paper to recycling**	**All paper to composting**
Climate change	-610	542	-654	-493	1555
Resource depletion	-1590	-697	-1701	-1296	1911
Acidification	-102	-10.2	-60.6	-235	1155
Aquatic eco-toxicity	-0.69	-34.2	-53.2	135	455
Eutrophication	-6.41	25.8	-3.01	-20	628
Human toxicity	-34.6	-7.48	-35.3	-38.9	119

(Note that the current scenario is based on 30% paper recycling with the remainder being gasified)

Table 8.2. The environmental effects of different types of paper waste management on the Isle of Wight (Europersons per year)

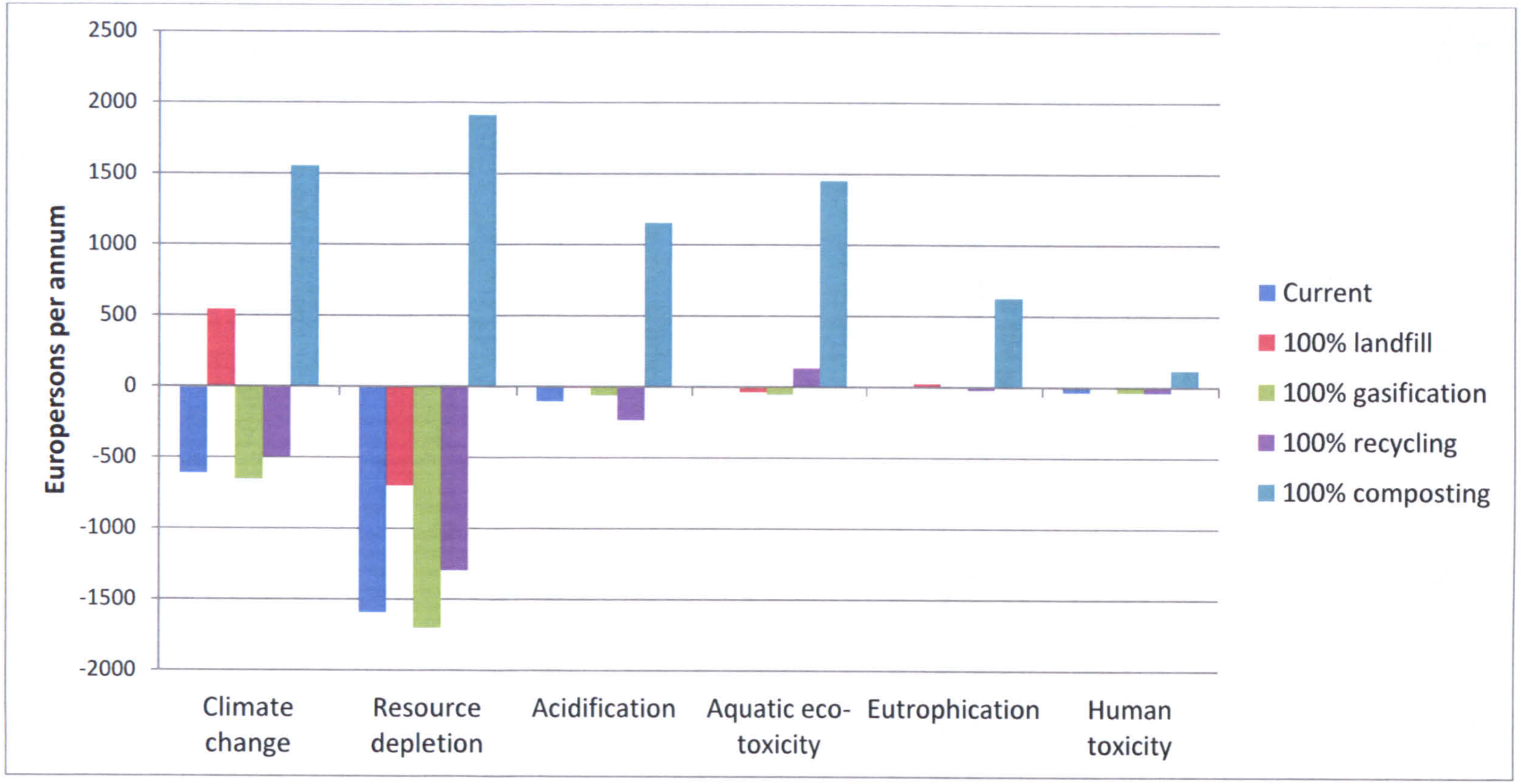

Figure 8.2. The environmental effects of paper waste management on the Isle of Wight.

Table 8.2 and Figure 8.2 show that, of the scenarios considered, composting all paper is the worst environmental option for paper waste. With the exception of climate change, composting performs less well than landfill. The results for composting are mainly due to the following causes:

- Climate change – the release of nitrous oxide and carbon dioxide to air during the treatment process,
- Resource depletion – the use of crude oil in transport and treatment,
- Acidification – the release of nitrous oxides to air during the treatment process,
- Aquatic eco-toxicity – the release of nickel ions, vanadium ions, barium and cobalt to water during the treatment process,
- Eutrophication – the release of ammonia, nitrogen and nitrous oxides to air during the treatment process,
- Human toxicity – the release of chromium VI to air and barium to water during the treatment process.

Thus the treatment of paper waste during the composting process is not environmentally beneficial and is worse than sending all paper to landfill. However, it should be noted that this scenario assumes that the applying the composted paper to land has no benefits. For example, it does not displace inorganic nitrate fertilisers which are energy and resource intensive to produce. This is probably a realistic assumption; the value of the paper in compost is to bulk and lighten the soil structure improving water drainage, water retention and aeration properties. However, it should be noted that this could be regarded as a conservative approach and further development of WRATE is necessary in this area.

Sending all the paper to landfill reduces resource depletion due to the recovery of energy from burning the proportion of the landfill gas that is captured. This displaces coal and gas as a fuel source. This also accounts for the reduction in eutrophication, toxicity and acidification. However, land-filling of paper increases climate change because not all the methane is captured by the gas recovery system.

The recycling of all paper is somewhat less beneficial than the current scenario. For climate change, the reduction in emissions of CO_2 to air is not so great when paper is recycled as compared to gasification and/or gasification with some recycling. As regards resource depletion, the recovery of energy from gasification is more beneficial than the reduction in virgin wood during recycling. The transport distances involved also increase resource use and climate change, as the gasification plant is on the Isle of Wight, whilst the recycling plant is in Kent. An even more hypothetical situation was also considered; the recycling of 100% of the waste paper generated. And the results are compared with the "realistic" scenario in Table 8.3.

Environmental indicator	Realistic scenario	100% recycling
Climate change	-493	-353
Resource depletion	-1296	-833
Acidification	-235	-1470
Aquatic eco-toxicity	135	365
Eutrophication	-20	-47.8
Human toxicity	-38.9	-47.2

Table 8.3. Comparison of realistic recycling with 100% recycling.

The main benefits from increasing the recycling rate are in the acidification category and due to reductions in sulphur dioxide and NO_x emissions associated with making paper from virgin sources. This table reinforces the findings of Table 8.2 in demonstrating that maximising recycling rates are not the best environmental option in all impact categories and the use of energy recovery may be better when measuring certain environmental effects. However, as mentioned in Section 7.14.4, the literature does suggest that recycling is generally better than the sole use of virgin materials to produce paper.

Considering gasification of the entire waste paper stream shows that, with the exception of acidification and eutrophication, this option is environmentally better than the current situation.

Based on the above information, the environmentally best option in terms of climate change, resource depletion and aquatic eco-toxicity is to process all the paper in a local gasifier. For the remaining categories, recycling at the maximum possible rate is the best option. However, it should be noted that the current scenario and gasification are the only scenarios that result in an overall reduction in impacts in all six categories.

The reason for carrying out this research was to be able to compare paper waste management options in environmental terms. It is also useful in highlighting the benefits and limits of some options. For example, if, for any reason, the Isle of Wight should choose to recycle all their paper, the information in Table 8.2 shows that it is aquatic eco-toxicity that is the main burden from the recycling process, mostly due to the release of nitrate ions to water. It would therefore be advantageous to look at the emissions to water and see where improvements could be made.

8.4 Current scenario for paper waste management on Shetland

The Shetland Islands disposed of approximately 6,370 tonnes of paper in 2008-2009 (30% of total waste tonnage) (Wastedataflow 2010). 101 tonnes of paper were sent to recycling, whilst most of the remainder was sent to the local incinerator, with recovered energy as heat. The waste system map is shown in Figure 8.3.

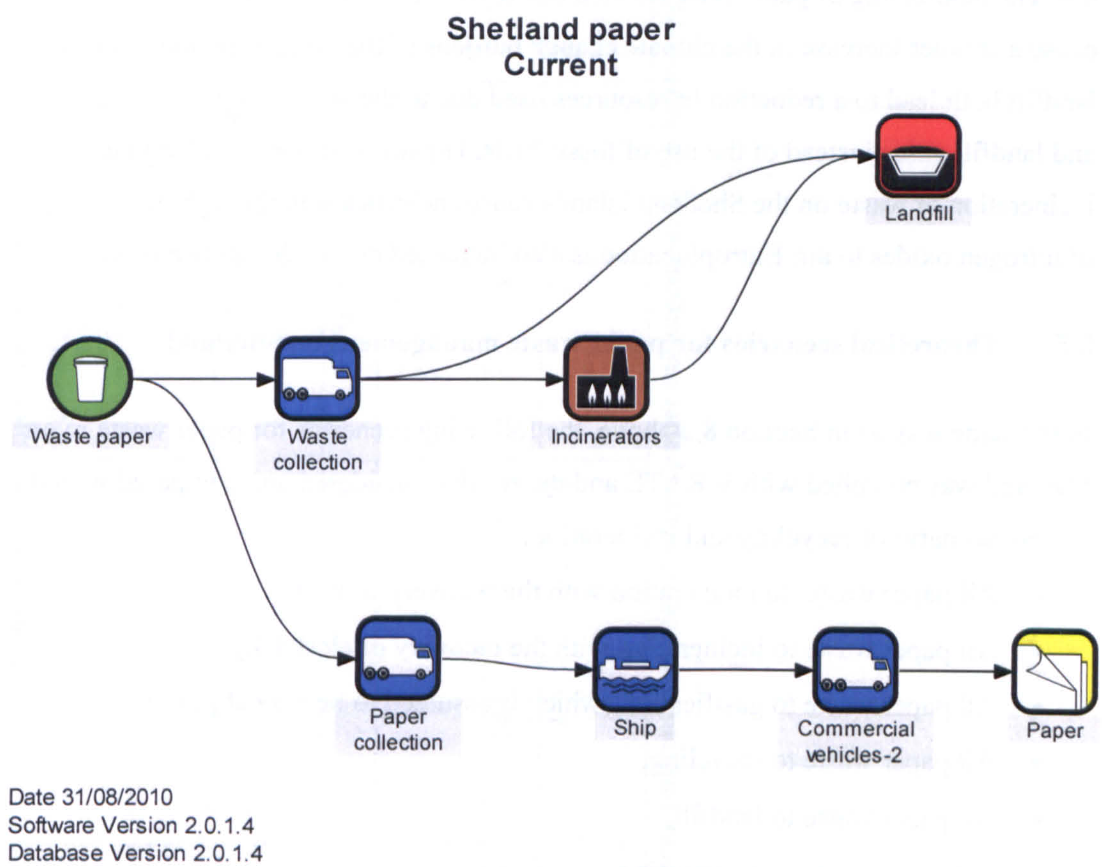

Figure 8.3. The waste system map for paper waste on the Shetland Islands.

The environmental effects of the current strategy are given in Table 8.4 below. All figures are in Europerson equivalents per year and negative burdens are in red.

Environmental indicator	Collection	Transport	MRF	Recycling	Incineration	Landfill	Total
Climate change	0.25	4.38	1.02	-2.58	-79	19.8	-56.1
Resource depletion	0.9	14.1	3.3	-7.22	-228	-26.2	-244
Acidification	0.05	4.57	0.8	-3.24	25.8	-0.708	25.6
Aquatic eco-toxicity	0.04	3.73	1.3	1.39	-3.66	2.51	5.28
Eutrophication	0.02	1.84	0.29	-0.555	11.8	0.974	14.3
Human toxicity	0.05	1.24	2.7	-0.421	0.181	0.326	4.02

Table 8.4. The environmental effects of the current waste paper strategy on the Shetland Islands (Europersons per year).

The incineration of waste on the Shetland Islands causes a reduction in CO_2 emissions to air and is the major contributor to the reductions in climate change shown in Table 8.4. The land-filling of paper releases methane to air and transport CO_2 to air, which cause a smaller increase in the climate change burdens of the system. Incineration and landfill both lead to a reduction in resources used due to the substitution of waste heat and landfill gases instead of the use of fossil fuels. However, it is noticeable that the incineration of waste on the Shetland Islands causes acidification, through the release of nitrogen oxides to air. Eutrophication is also increased due to the same emissions.

8.5 Theoretical scenarios for paper waste management on Shetland

In the same way as in Section 8.2 above, the following scenarios for paper waste in on Shetland was modelled with WRATE and the results considered and compared with the current scenario of recycling and incineration:

- All paper waste to incineration with the recovery of heat,
- All paper waste to incineration with the recovery of electricity,
- All paper waste to gasification (which is assumed to be a local plant),
- All paper waste to recycling,
- All paper waste to landfill,
- All paper waste to composting.

The results for Shetland are given in Table 8.5 and Figure 8.4 below. All figures are in Europersons per year.

Environmental Indicator	Current	All paper to incineration +heat	All paper to incineration + power	All paper to gasification	All paper to recycling	All paper to landfill	All paper to compost
Climate change	-58	-113	-90	-87	-38	74	203
Resource depletion	-250	-327	-248	-234	-106	-87	246
Acidification	26	41	0.76	-7	-57	0.08	151
Aquatic eco-toxicity	3	3	-4.4	-6.09	49	-3	61
Eutrophication	14	19	8	0.5	-4	4	82
Human toxicity	1	2	-3	-4	-6	-0.4	16

Table 8.5. The environmental effects of waste paper management in the Shetlands. (Europersons per year)

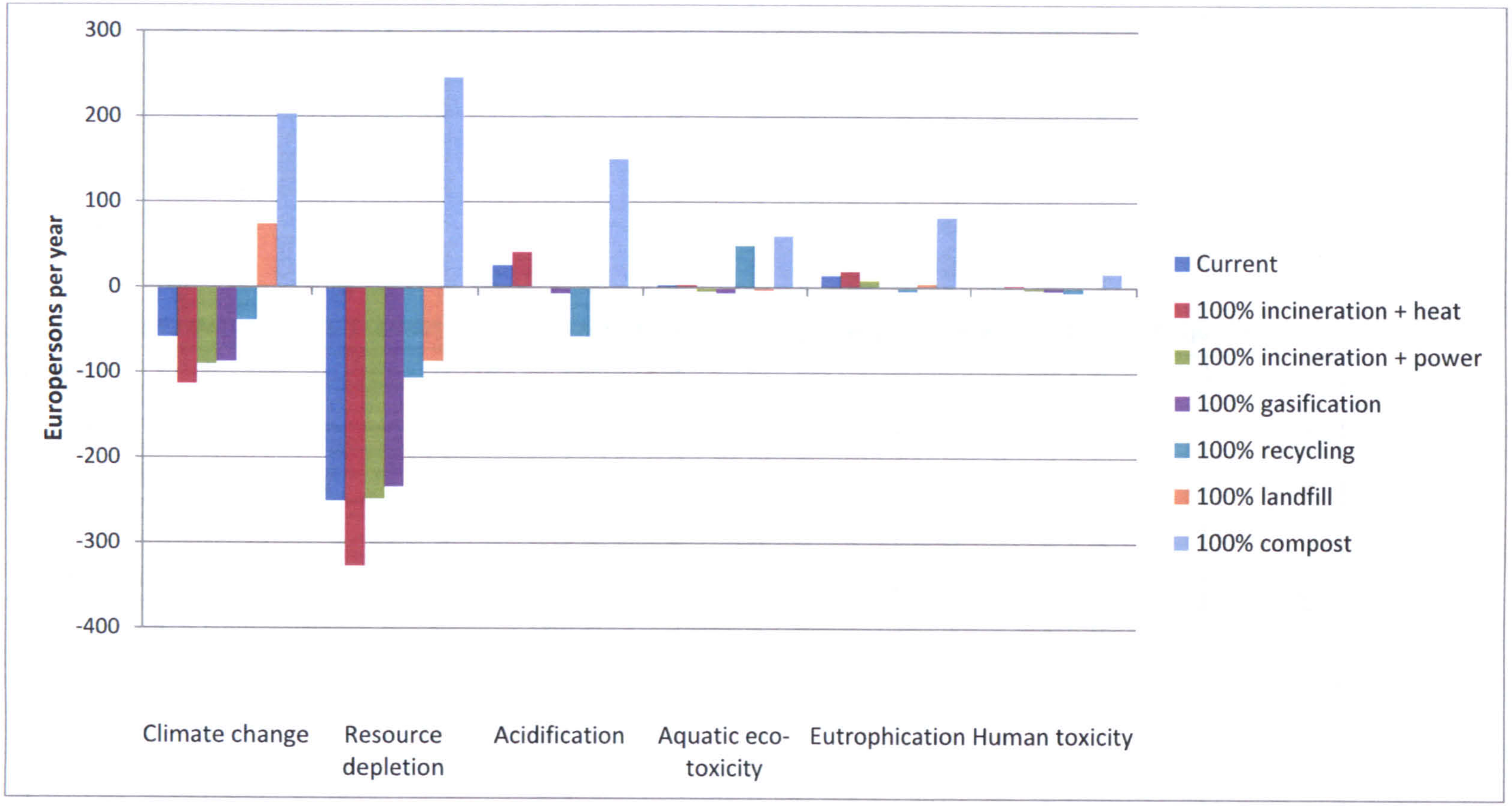

Figure 8.4. The environmental effects of paper waste management in the Shetland Islands. (Europersons per year).

From Table 8.5 and Figure 8.4 the following points can be made:

As with the management of Isle of Wight paper waste, the sending of all paper to composting is clearly the least beneficial for the environment. The use of fuel for shredding, screening and turning the windrows during the composting process and the insignificant benefits from applying the compost to land mean that all the measured environmental indicators are positive.

Incineration with the generation of heat is the best option as regards climate change and resource depletion, due to the reductions in the use of natural gas and the emissions of CO_2 to air during the treatment and recovery processes.

Incineration with heat performs better than incineration with power in climate change and resource depletion categories. As discussed elsewhere, this is due to the higher thermal efficiency of the heat system (80% against 21%). However, in the remaining categories, power generation is the better option. This is due to:

Acidification – Increased NO_x and SO_2 emissions to air from the heat-producing incinerator in comparison with the gas-fired heating that is displaced.

Aquatic eco-toxicity – This is due to a combination of the reduction in discharge of vanadium and tributyl tin compounds to water from reduced coal-fired emissions in the case of power and an increase in copper, nickel and cobalt from the displacement of gas by waste in the case of heat.

Eutrophication – This is caused by the increase in NOx emissions when gas heating is replaced by waste.

Human toxicity – increased thallium emissions to air from heat production. However, the thallium emissions used by WRATE are an estimate, so in reality may be over or under the figures quoted here.

All paper waste to gasification is slightly better than the current system for climate change and slightly worse for resource depletion and better for all the other categories. However, if the true transport distances needed to gasify paper waste had been inserted in to WRATE (1880 km to nearest gasification plant on the Isle of Wight) this would have increased the burdens on the environment significantly when measuring both these variables (See Section 7.16.4).

Overall the WRATE results show that recycling is the best option in three categories, heat recovery is the best option in two and gasification in one. Therefore there is no clear-cut best option. However, as with the results from the Isle of Wight, the WRATE comparisons and results allow an examination of a particular option, its benefits and disadvantages and the need for any improvements to the waste management option.

8.6 Current scenario for paper waste management in Nordfjord

Nordfjord currently disposes of approximately 2270 tonnes of paper per annum (NoMil 2010). The current paper waste management involves sending 1267 tonnes for recycling, the rest being disposed of via waste incineration with heat recovery.

The environmental effects of the current paper waste management practice are given in Table 8.6 below.

Environmental indicator	Collection	Transport	MRF	Recycling	Incineration	Landfill	Total
Climate change	0.15	16.3	0.3	-29.4	-46.3	0.0198	-58.8
Resource depletion	0.6	45.8	1.13	-82.3	-102	0.138	-136
Acidification	0.03	14.6	0.2	-37	-17.3	0.0282	-39.3
Aquatic eco-toxicity	0.01	7.89	0.4	15.8	-10.6	1.54	15.5
Eutrophication	0.01	5.93	0.05	-6.33	-1.42	0.0469	-1.78
Human toxicity	0.03	2.76	0.07	-4.79	-3.83	0.261	-5.5

Table 8.6. The environmental effects of the current waste paper management system in Nordfjord (Europersons per year).

From table 8.6, it can be seen that the main decreases in environmental burdens are a result of recycling and incineration with heat recovery. The main increases in burdens are due to the transport of waste to the treatment sites in Norway. As with the Isle of Wight and the Shetland Islands, transport increases the climate change burdens due to a release of CO_2 to air, whereas recycling and waste to heat incineration result in a decrease in CO_2 release because the use of recycled materials is less energy intensive than producing materials from virgin sources and the production of heat substitutes fossil fuel use. As regards the depletion of resources, transport causes an increase due to the use of oil derivatives, whilst incineration and recycling cause a decrease in burdens due to reduced fossil fuel use. Acidification is increased by the release of nitrogen oxides and sulphur dioxide to air during transport, but is decreased by recycling and incineration as emissions of these pollutants is reduced during these treatment options. The release of trace elements to water is the cause of the increased aquatic eco-toxicity as a result of transport and recycling. These burdens are decreased by incineration.

The banning of biodegradable waste from landfill sites in Norway means that the effects of landfill on the Isle of Wight and the Shetland Islands are not present in the Norwegian waste paper management system.

8.7 Theoretical scenarios for paper waste management in Nordfjord

Nordfjord disposed of approximately 2000 tonnes of paper and card in 2008-2009 (Sunnfjord Miljøverk 2011). WRATE was used to model the same set of scenarios for paper waste management as were used in the case of Shetland in Section 8.4. The results are shown in Table 8.7 and Figure 8.5.

Overall, the findings are similar to those from Shetland and the Isle of Wight, but the following points also arose.

The poor performance of composting demonstrates that the disadvantages of composting are irrespective of the country involved and more to do with the emissions related to the mechanical composting process and the lack of benefits from compost use.

The power recovery and gasification options both contribute to adverse environmental impacts in all categories. As discussed in Chapter 7, this is because the waste-derived power produces environmental emissions, and displaces emission-free hydropower. In reality, hydropower is not without environmental impacts; in particular those relating to land-use, ecosystem damage and ecosystem loss. However, there is no recognised way of assessing these impacts so they are not included in WRATE, or indeed in other conventional LCA tools.

Environmental Indicator	Current	All paper to incineration +heat	All paper to incineration + power	All paper to gasification	All paper to recycling	All paper to landfill	All paper to compost
Climate change	-59.3	-81.3	21.6	19.5	-31.1	78	157
Resource depletion	-138	-229	54	54	-87	5.13	209
Acidification	-39	15	30.3	24.5	-44.7	5.07	120
Aquatic eco-toxicity	14.7	2.52	15.7	13.1	32.5	1.04	48.9
Eutrophication	-1.78	11.8	14.7	9.79	-4.46	4.04	63.6
Human toxicity	-5.6	-4.48	5.14	4.29	-5	1.21	13.3

Table 8.7. The environmental effects of waste paper management in Nordfjord. Europersons per year.

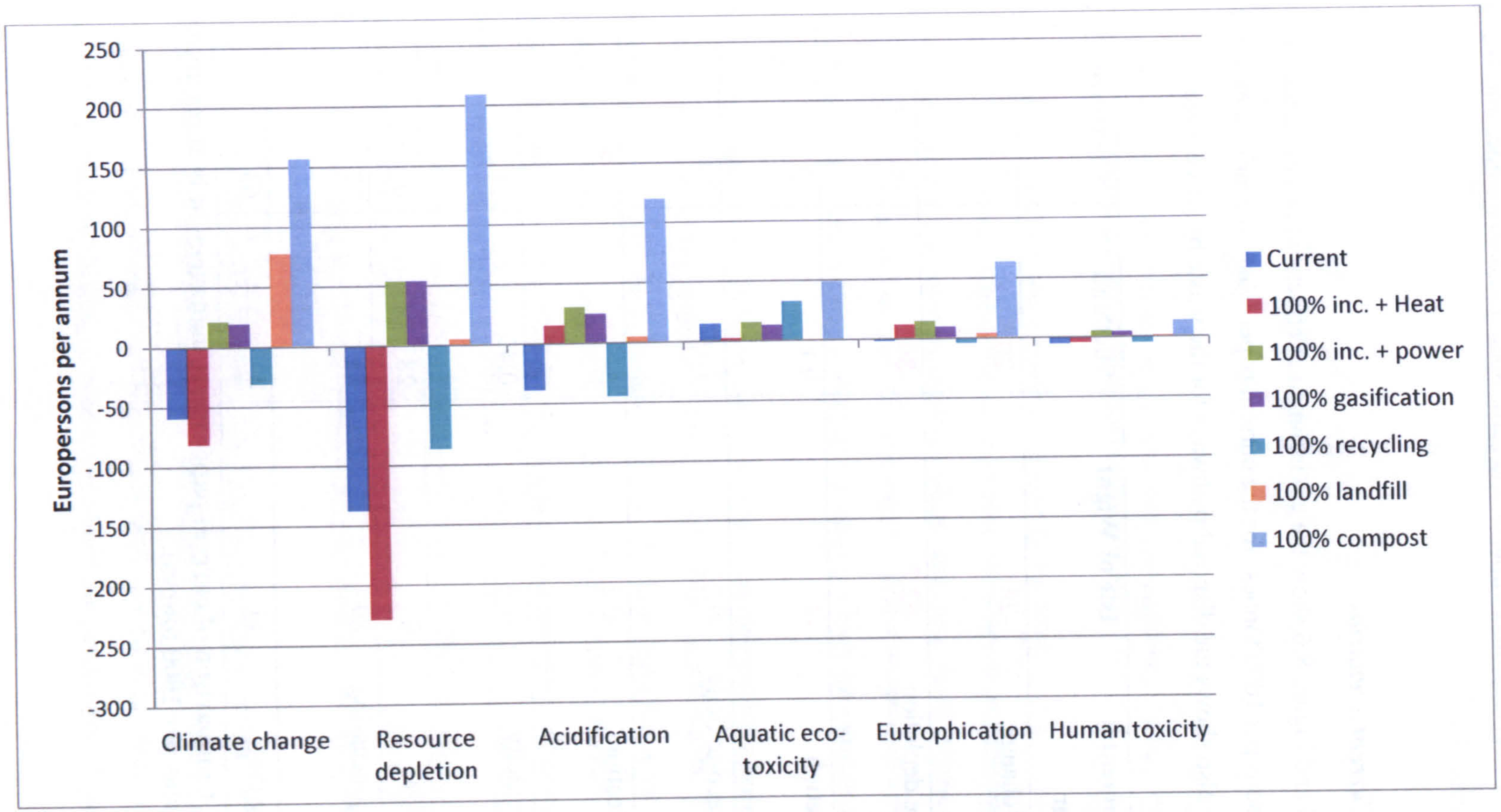

Figure 8.5. The environmental effects of waste paper management in Nordfjord. Europersons per annum.

8.8 Comparison of the waste management systems in the three communities

As with the complete waste stream, to compare the current paper waste management of the Isle of Wight with other areas on an equal basis, the figures need to be converted to europersons per 1000 tonnes paper waste managed. In 2008-09 the Isle of Wight disposed of 25,400 tonnes of paper and card, Shetland, 6,400 tonnes and Nordfjord 2,000 tonnes.

8.8.1 Current Scenarios

Table 8.8 and Figure 8.6 show the environmental effects when converted to 'Europersons per 1000 tonnes' for the current paper waste scenario in each location. The table also shows the disposal pathways for the waste by percentage.

Environmental indicator	Isle of Wight	Shetland	Nordfjord
Climate change	-24	-20.5	-30
Resource depletion	-62.7	-89	-69
Acidification	-4	9.1	-20
Aquatic eco-toxicity	-0.02	1.14	7.4
Eutrophication	-0.25	5	-0.9
Human toxicity	-1.4	0.45	-3
Landfill (%)	0	28	0
Thermal processing (%)	89	68	37
Recycling (%)	11	4	63

Table 8.8. Comparison of current paper waste management in three areas. (Europersons per 1000 tonnes).

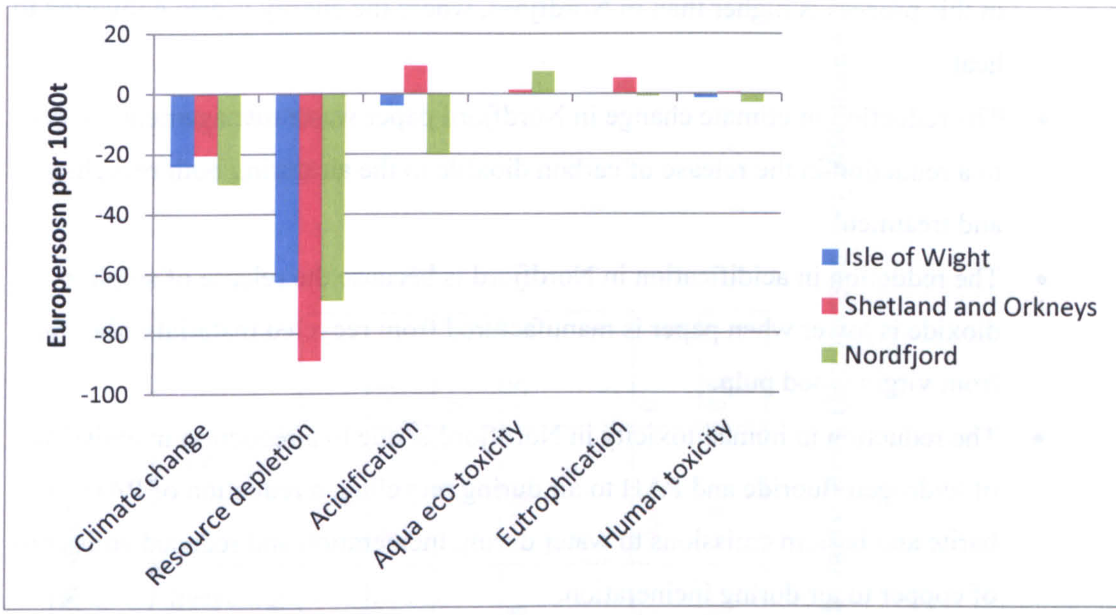

Figure 8.6. The comparison of current paper waste management in the three different areas. Europersons per 1000 tonnes paper waste.

From Table 8.8 and Figure 8.6, the following points can be made:

- All three areas follow roughly the same pattern, showing large benefits in resource depletion, followed by climate change and, to a lesser extent, acidification. This would suggest that the paper waste management systems are more beneficial in these categories than the others, which are more or less neutral.
- The paper waste system in Nordfjord is the most environmentally beneficial of the three areas in all but resource depletion and aquatic eco-toxicity. The increase in eco-toxicity in Nordfjord is due to an increased release of vanadium, polycyclic aromatic hydrocarbons (PAH), nickel ions, cobalt, barium, barite and tributyltin compounds to water during transport and increased emissions of copper ions and vanadium to water as a result of the recycling process. Transport causes increased resource depletion as the distances waste is transported in Norway are larger than the other two areas. Thus the total for resource depletion in Nordfjord is less beneficial than it could otherwise have been.
- Resource depletion in Shetland is more beneficial because, unlike the other areas, the impacts from transporting paper waste away from the area are negligible. The use of paper in incineration with heat recovery means that the use of fossil fuels for heating is also reduced and the percentage of paper used

in this process is higher than in Nordfjord, where the energy is also converted to heat.

- The reduction in climate change in Nordfjord paper waste management are due to a reduction in the release of carbon dioxide to the air during both recycling and treatment.
- The reduction in acidification in Nordfjord is because the release of sulphur dioxide is lower when paper is manufactured from recycled material rather than from virgin wood pulp.
- The reduction in human toxicity in Nordfjord is due to a reduction in emissions of hydrogen fluoride and PAH to air during recycling, a reduction of PAH, barite and barium emissions to water during incineration and reduced emissions of copper to air during incineration.
- The smaller reductions for the Isle of Wight climate change impact is caused by a reduction in the release of carbon dioxide and methane to air during recycling and treatment.
- The saving in resources for the Isle of Wight are caused by a reduction in the use of coal and oil during recycling (in comparison to virgin fibre for paper production) and a reduction in the use of coal gas and oil in the treatment process as the energy from gasification replaces fossil fuels.
- The negative values for acidification on the Isle of Wight are due to a reduction in the emissions of sulphur dioxide and nitrogen oxides to air as a result of recycling and a reduction in the emissions of sulphur dioxide to air during the treatment process.
- Shetland shows an increase in acidification, where the other two areas are negative due to emissions of nitrogen oxides (NOx) to air during transport and incineration. The gasification plant on the Isle of Wight and the incineration plant in Norway do not have these positive values for NOx although the systems do have similar positive NOx emissions from transport.

Within the above data there are generally positive emissions for transport in all environmental categories and, to a lesser extent, landfill which are outweighed by the negative figures for recycling and treatment, but still significant. This is shown in Table 8.9 and Figure 8.7 below.

	Isle of Wight				Shetland				Nordfjord			
Indicator	Transport	Recycling	Energy	Landfill	Transport	Recycling	Energy	Landfill	Transport	Recycling	Energy	Landfill
Climate	1.1	-2.1	-23.4	0	0.7	-0.4	-12.4	3.1	16.3	-29.4	-46.3	0
Resources	3	-6	-62	0.2	2.2	-1.1	-35.8	-4.1	45.8	-82.3	-102	0.1
Acidification	0.9	-2.7	-2.5	0	0.7	-0.5	4.1	-0.1	14.6	-37	-17.3	0
Aquatic eco-toxicity	0.6	1.2	-3.4	1.5	0.6	0.2	-0.6	0.4	7.9	15.8	-10.6	1.5
Eutrophication	0.4	-0.5	-0.2	1.1	0.3	-0.1	1.9	0.2	5.9	-6.3	-1.4	0
Human toxicity	0.2	-0.4	-1.5	0.2	0.2	-0.1	0	0.1	2.8	-4.8	-3.8	0.3

Table 8.9. Emissions for the significant system components of paper waste management in the three areas. (Europersons per 1000 tonnes waste).

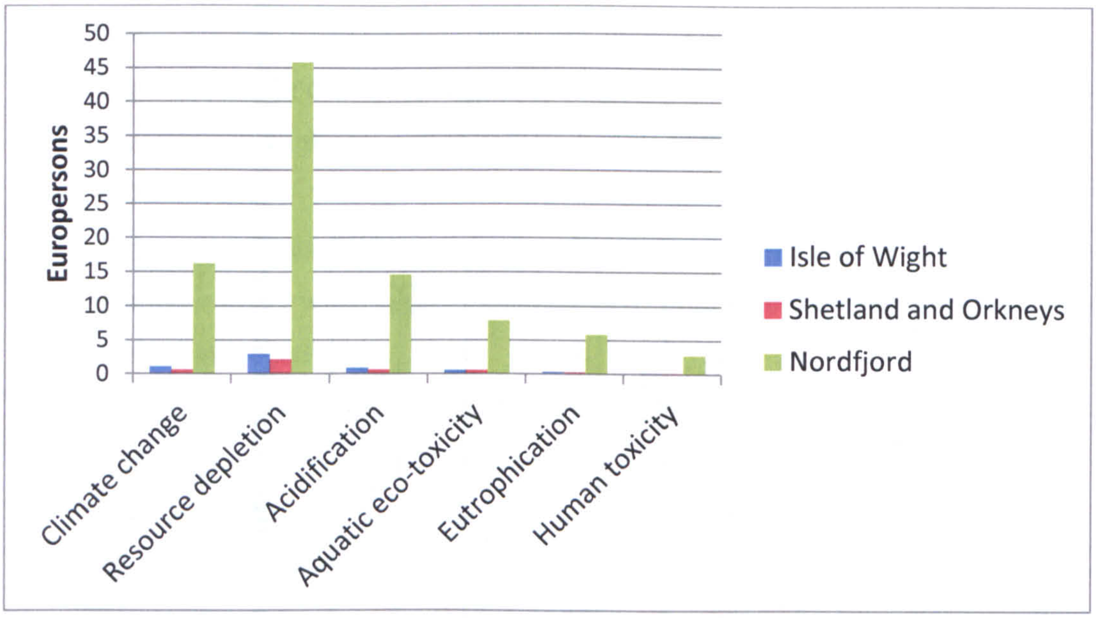

Figure 8.7. The environmental effects of transport in the paper waste management systems of the three areas. (Europersons per 1000 tonnes paper waste).

Thus, the environmental effects of transport are considerably higher in Norway than the other two areas, which is a reflection of the long distances the paper waste management system uses.

8.8.2 Current recycling comparisons

To allow a straight comparison of current materials recycling in the three study areas, the impacts (per 1000 tonnes treated) are summarised in Table 8.10.

	Recycling		
Environmental indicator	**Isle of Wight**	**Shetland**	**Nordfjord**
Climate change	-18	-14	-16
Resource depletion	-49	-39	-44
Acidification	-25	-21	-22
Aquatic eco-toxicity	15	18	16
Eutrophication	-3	1.4	-2.2
Human toxicity	-3	-2	-3

Table 8.10. Impacts of materials recovery (Europersons per 1000 tonnes).

This table confirms the previous findings in that these results are only influenced by the transport impacts and show broadly similar values, with the benefits decreasing as transport distances increase (IoW<Nordfjord<Shetland). Thus treatment options which reduce the use of transport will also reduce the environmental burdens, which should be important in paper waste management decision-making.

8.9 Summary of the use of the WRATE LCA model

To summarise, the findings of the WRATE process for paper waste management are:

- Composting all the paper waste is the least beneficial environmental option for all three areas.
- The present scenarios are relatively good compared to the theoretical scenarios, but in each of the areas there are better options which reduce environmental burdens.
- Transport and landfill should be kept to a minimum from an environmental point of view
- The benefits of incineration are dependent on the kind of fuel the recovered energy is replacing.

8.10 Criticisms of the use of WRATE

The use of WRATE in such a detailed study has identified a number of weaknesses of the tool, but is must be stressed that these problems would apply equally to any other LCA tool.

WRATE is dependent on reliable and accurate input data. In many cases, such as the tonnage managed in a particular way and the emissions from transport processes, suitable data are readily available, either from WRATE or from the areas concerned. However, WRATE also requires a detailed breakdown of the waste composition. To obtain such information is expensive, time consuming and of limited value to the operations staff. Therefore, UK average values had to be used when considering mixed household waste, which will lead to some inaccuracies. In addition, WRATE does not have a comprehensive emissions inventory for every waste treatment process. For example, the thallium emissions from gasification (which appear to be significant) are based on estimated values from other plants.

Although extensive, the databases used by WRATE are a simplification of the realities of the environmental impacts of a waste management process. For example, there are no time-scales for the different emissions (particularly important with respect to landfill) and their effects on the local communities (some emissions are longer-lived than others) and there are no differences accounted for in the local geography and the way this affects pollutants. However, as with the financial data, the different waste management options within an area will all be affected in the same way and therefore valid conclusions can be made. The comparisons of the different areas with each other must bear these factors in mind.

Due to this need for simplification when using a model to examine real-life scenarios, there are standard inputs into the WRATE database which affect the results; all rubbish sacks are of one kind; a standardisation of collection and transport vehicles; a standardisation of treatment plants. The sacks and vehicles will not significantly affect the comparisons in this thesis as both internal and external comparisons are affected by the same factor. Treatment plants, however, do differ but with no public data available for comparison it is not possible to judge how significant these differences are.

WRATE allows the user to select the fuels used to generate the power that is displaced by waste-derived power. In this thesis, the average mix was used for the UK and Norway. However, it can be argued that in the UK, the correct fuel to displace would be gas because gas-fired capacity is the easiest to shut down and gas also presents the highest fuel cost (Burnley et al 2011). Equally, it could be argued that a reliable waste-derived power plant would displace coal, because coal has the highest carbon content of the fossil fuels and would be the first fuel to replace in a strategy aimed at reducing carbon emissions.

Unless the user has access to other sources of data, it is not possible to specify the fuels saved through paper recycling. WRATE assumes an average European value which means that the benefits (particularly for climate change) will be over-estimated if the paper mill that manufactures the displaced paper is fired by renewable sources (biomass or hydropower for example) and under-estimated in the case of a fossil fuel fired paper mill.

Little data are available on the distances travelled by refuse collection vehicles undertaking kerbside collections of waste and recyclables (Burnley et al 2011). For the Isle of Wight and Shetland, collection round data from North Hampshire were used, which presents another source of inaccuracy. This would not affect the comparisons of different waste management options within an area, but could affect the comparisons between areas. It is reasonable to assume that rural North Hampshire, with a similar assize and population density to the Isle of Wight will have similar collection round characteristics to the Isle of Wight. However, the collection distances in Shetland, will be higher than in Hampshire, so the WRATE analysis will underestimate the collection-related impacts in Shetland. The conclusions from the WRATE results that collection transport needs to be kept to a minimum will be strengthened rather than weakened by these inaccuracies.

Chapter 9 Results and discussion – Multi-Criteria Decision Analysis of paper waste management

9.1 Introduction

The MCDA workshop was set up specifically to look at the social aspects of paper waste management on the Isle of Wight. Two introductory presentations were made to the panel: first, the aims of the research, the findings from the WRATE LCA research, the financial findings and the role of the workshop; second, the technical aspects of the waste management options, the national legislation and targets for waste in England and the use of LCA as a tool.

The results of the financial and LCA assessments described in Chapters 6 and 8 were used by the MCDA panel, with the emphasis on the results for the Isle of Wight as this is the area the workshop was considering.

9.2 Information presented to the MCDA workshop

The legislative targets from the EU Directives that the UK is obliged to follow were presented. The resulting national legislation was also described.

The results from the financial research which were presented to the panel were for the Isle of Wight (from Chapter 6) and are given in Table 9.1. It was noted that sending all paper to landfill was the cheapest option at the current time, although the costs will increase to an equivalent level to the other waste management options in 2020, due to the increase in landfill taxes. Apart from the landfill option, sending all the paper to gasification was stated as the cheapest method of disposal.

	Current scenario	100% landfill	100% gasified	100% recycle	100 % composted	100% incinerated
Total	£142.83	£97 (£122 in 2020)	£132	£148.63	£155	£146.35

Table 9.1. Cost of paper waste management on the Isle of Wight (£ per tonne).

Although these results are for the complete waste stream, the panel was informed that the costs of sending paper to the various options would not be significantly different as the collection, transport and gate fee costs are similar for paper waste.

The following results from the WRATE LCA research were presented to the panel:

- Composting all the paper waste is the worst environmental option.
- The present scenario, with 70% recycled and most of the remainder sent for gasification, is environmentally relatively good compared to the theoretical scenarios. However, the environmentally best option in terms of climate change, resource depletion and aquatic eco-toxicity is to process all the paper in a local gasifier. For the remaining categories (acidification, human toxicity and eutrophication) recycling at the maximum possible rate is the best option.
- The current scenario and gasification are the only scenarios that result in an overall reduction in impacts in all six categories.
- Transport and landfill should be kept to a minimum from an environmental point of view
- The benefits of incineration are dependent on the kind of fuel the recovered energy is replacing.

The social aspects to be considered were listed, but left to the panel members to discuss in group sessions.

9.3 Group Discussions

Following the presentation of the legislative, financial and environmental data and the general presentation on the six paper waste management options shown in Table 9.1, the whole group and then the two sub groups discussed the presentations in general terms before setting the weighting factors and rankings.

9.3.1 Comments from Group 1

The comments from Group 1 were varied and with obvious differences of opinion and ideas from the participating members.

Some of the comments were specific to the Isle of Wight. For example, the gasification plant has been out of commission since April 2010 and this was discussed, especially the doubts about the efficacy of having a gasification plant when it is not functioning. However, the representative from Biffa explained that the technology of gasification is good; it is the fact that it has been added on to an old incinerator which is causing the present problems and the reasons for the higher than normal emissions when the plant is in operation.

In response to the WRATE findings, an employee of a waste management company said that they had done a similar examination of the environmental costs of waste management and come to the same conclusions; that the gasification of waste was environmentally the least detrimental for the environment and that the transport of waste away from the island was detrimental, both environmentally and economically.

There were also comments about waste management in general. It was explained that gasification technology was suited to a small geographical area and a smaller population due to the modular method of building the plants, which means they can take smaller amounts of waste. One group member was interested in the economics of smaller plants, which do not have a large turnover of waste. However, it was mentioned that this problem will be reflected in the gate fees charged by the smaller gasification plants. It was also noted that gasification has been shown to be more socially acceptable as an industry than the other incineration plants, which are historically suspected of emitting dioxins. This meant that the local population did not react to planning applications for a gasification plant in a negative way.

As regards recycling, there was one group member who emphasised the 'feel-good factor' when recycling waste and separating waste at the civic amenity site. The 'feel-good' factor is an important part of the recycling process and adds to the participation level from households and individuals. In any waste management planning it is important to encourage participation and interest from the local population and, therefore, recycling is important for this reason as well as for the recovery of materials.

In response to the economic findings presented to the groups, it was agreed that composting is not as cheap a process as is generally believed. The regulatory standards for the finished product and the processes involved in meeting these standards are expensive.

The legislation behind waste management was also a topic for discussion. The Landfill Directive and national legislation target the diversion of waste from landfill and the Isle of Wight over-achieves on the 36% required. Recycling and composting together is 30-35% which does not achieve the national targets. The discussion centred on the differences between recovery, which is achieved by the recovery of energy as well as materials, and recycling, where paper waste is used to produce new paper or card.

9.3.2 Comments from Group 2

As in Group 1, this group had a wide range of ideas and attitudes to paper waste management which was reflected in the discussion, both for weighting and for ranking.

Specific to the situation on the Isle of Wight, there was general agreement that the island is an insular place and people are generally sceptical to change. For any waste management option to get planning permission, it is necessary for it to be acceptable to the local population; this has been confirmed by the reaction to wind farms on the Isle of Wight, where local action against them prevented the council from giving the necessary planning permission (BBC News 2006).

In addition to being insular, the group agreed that the demographics of the island are such that the local population are not generally bothered about what they do to the environment. The group felt that due to the high number of elderly people living on the island, worries about the future were less important and therefore the environment was less of a concern. This feeling, if it is the case, would tend to compensate for the insular characteristics described above, where new projects are met with scepticism and rather cause a decrease in people's engagement in the planning processes.

Another member of the group was interested in the natural environment on the Isle of Wight. The comment was that legislation and national targets change and are ephemeral, the beauty of the island is more important. Thus the effects of waste management on the environment were more important than legislative targets. However, other group members disagreed, stating that we are bound to follow legislation, so this is a very important criterion.

When discussing the weighting of the social factors, Group 2 felt that human health and the affect on the environment of any waste management option were the most important. However, it was also argued that human health is not affected by paper waste management, whilst other group members felt that human health could be affected by any errors in management that lead to increased emissions or other failures in the system.

Tourism was not seen as important, as the members of the group meant that waste paper management was not 'seen' by tourists and thus any change in the system would not affect people's wish to holiday on the island.

Legislation was felt by some to be important as a driver for targets, both for emission levels and for diversion from landfill. Others meant, as mentioned above, that legislation changes dependent on the politics of the day and this reduces its importance. There was also the comment that it is better to pay fines for not achieving legislative targets if this meant that the local environment was conserved for later generations. However, one of the group members argued that legislation affects the cost of an option and will therefore affect the decision-making process. In addition, cost will affect the social acceptability of an option.

Jobs were also seen as less important, as changes in paper waste management would not affect jobs.

9.3.3 Group dynamics

As with all such social groupings, the MCDA workshop and the two groups involved were more dominated by some of the members, whilst others were quieter. However, the small sizes of the groups and the informal atmosphere meant that all the members contributed and all comments were heard and discussed in a positive manner. Given the small group sizes, formal facilitation was not considered necessary. It was decided that the process would be aided by an informal structure, where the participants could enter into conversation with each other in a 'safe' setting and exchange views and ideas (Berghold and Thomas, 2011). The author and one of the research supervisors (SJB) were present to assist the groups when requested.

The preparation of the topic for the presentations was aimed to stimulate the discussions and encourage interaction between the participants. The need to be neutral when the groups were discussing the weighting of variables and the ranking of the paper waste management options was crucial to the running of the workshop.

The presence of the informal facilitators did prove necessary to answer technical and practical questions and, to a lesser extent, to make sure the groups kept within the time frame, whilst covering all the necessary material. This role would almost certainly have become more important if the exercise was being undertaken in a real situation or if any group members had firmly entrenched views (for example on the use of thermal processing technology).

It was also important that the participants discussed the subjects with each other, rather than with the facilitators, so that it was their views that were registered rather than the views of the researchers. The two supervisors were attentive to the discussions and views being expressed, taking notes which were analysed after the panel workshop was completed.

9.4 Weighting factors

After discussing the relative importance of the environmental, financial and social factors, the two groups, working independently, produced the values shown in Table 9.2.

The idea of a panel as a decision-making tool for social factors is to reduce the subjectivity of the conclusions. All the weighting and ranking scores are duly a compromise after discussions within the groups, which also gives a more balanced view of the social issues being considered. However, as mentioned above, it must also be remembered that there are always some members of a panel who are more forceful in their ideas than others and that this could skew the results.

Social factor	Group 1	Group 2	Difference in scores
Impact on the environment	15	19	4
Human health	15	16	1
Jobs	5	6	1
Cost	20	14	6
Social acceptability	20	19	1
Tourism	5	10	5
Legislation and national targets	20	16	4
Total	**100**	**100**	-

Table 9.2. Weighting scores for social factors on the Isle of Wight.

From Table 9.2 it can be seen that the weightings of the social factors follow a similar pattern for each group, with tourism and jobs less important and social acceptability one of the most important for all the panel members. Environmental and human health was weighted highly by both groups. The cost of the waste management option was considered one of the most important factors by Group 1, but less important by Group 2.

From the differences between the scorings (column 3) it can be concluded that the groups agreed on the weighting of human health at 15.5 (quite high), jobs at 5.5 (low) and social acceptability at 19.5 (high). The other social factors have larger differences; environmental health – quite high to high, cost – high to quite high, tourism – low to quite low, legislation – high to quite high. Even with these differences, the general pattern of scoring is similar and this fact would tend to suggest that any influencing of decisions by one group member or another has not been too significant.

9.5 Ranking

The results of the ranking process for Groups 1 and 2 are shown in Tables 9.3 and 9.4 and Figures 9.1-9.7.

Options	Current	Landfill	Gasify	Recycle (m)	Recycle (i)	Compost	Incinerate (m)
Environment	4	2	6	3	4	2	4
Human health	5	5	6	3	4	2	4
Jobs	5	2	3	3	4	3	2
Cost	6	2	6	2	3	4	3
Acceptability	5	4	6	7	6	6	2
Tourism	2	1	4	6	6	3	2
Legislation	3	1	3	6	6	6	2

Table 9.3. Ranking of paper waste management options on the Isle of Wight, Group 1. m = on the mainland, i = on the Isle of Wight.

Options	Current	Landfill	Gasify	Recycle (m)	Recycle (i)	Compost	Incinerate (m)
Environment	6	3	7	4	5	1	5
Human health	6	6	6	6	6	6	6
Jobs	3	4	2	3	7	4	1
Cost	4	3	7	2	1	6	5
Acceptability	2	1	6	5	7	7	4
Tourism	3	1	4	4	6	7	2
Legislation	3	1	5	6	7	5	4

Table 9.4. Ranking of paper waste management options on the Isle of Wight. Group 2. m = on the mainland, i = on the Isle of Wight.

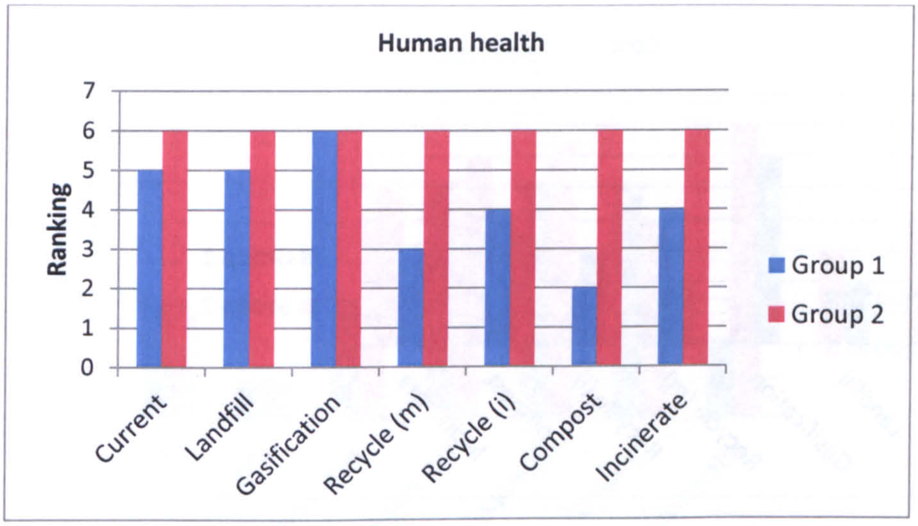

Figure 9.1. Ranking of waste management options in terms of human health

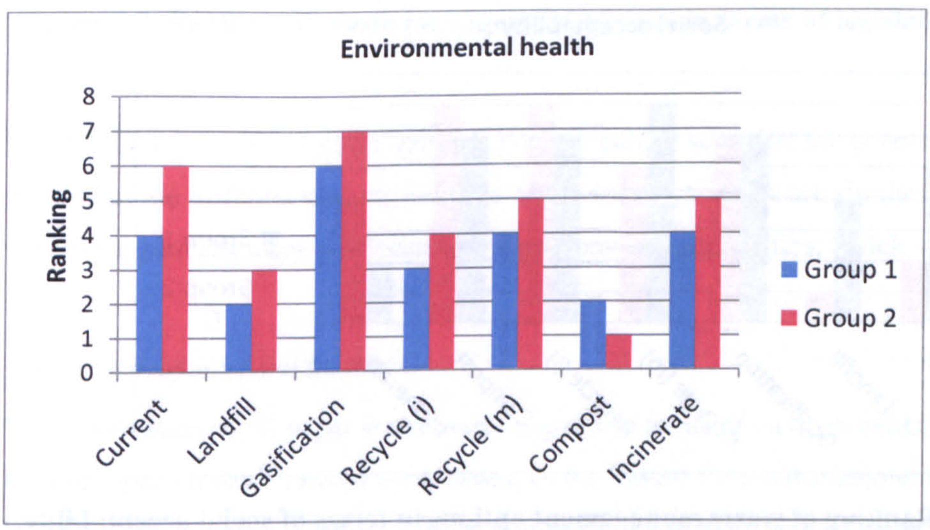

Figure 9.2. Ranking of waste management options in terms of environmental health

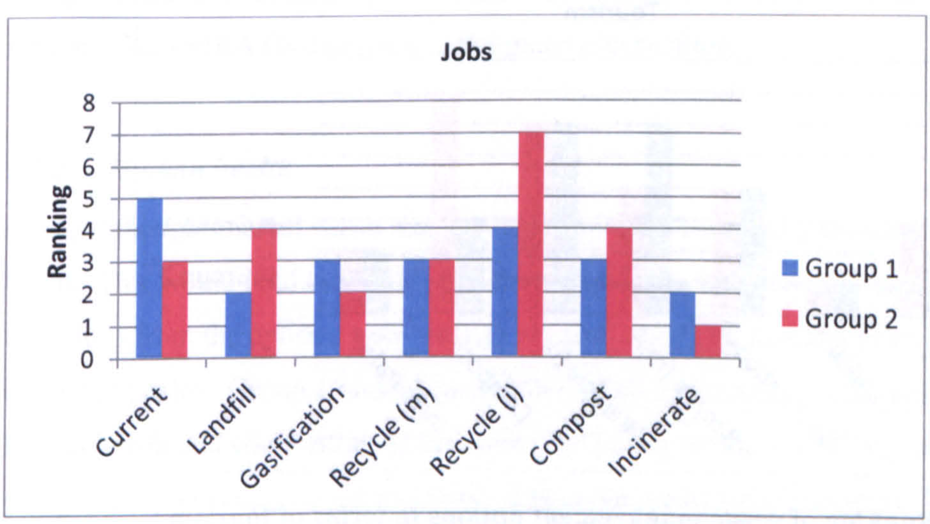

Figure 9.3. Ranking of waste management options in terms of jobs

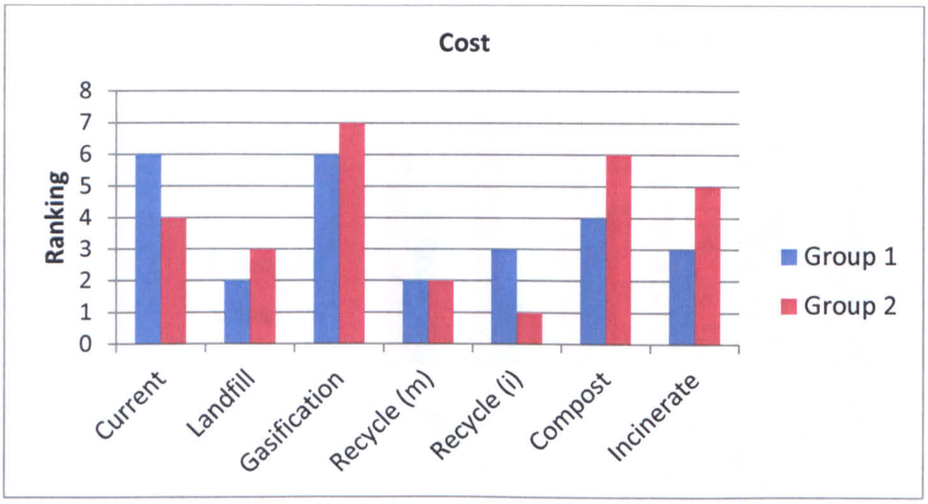

Figure 9.4. Ranking of waste management options in terms of cost

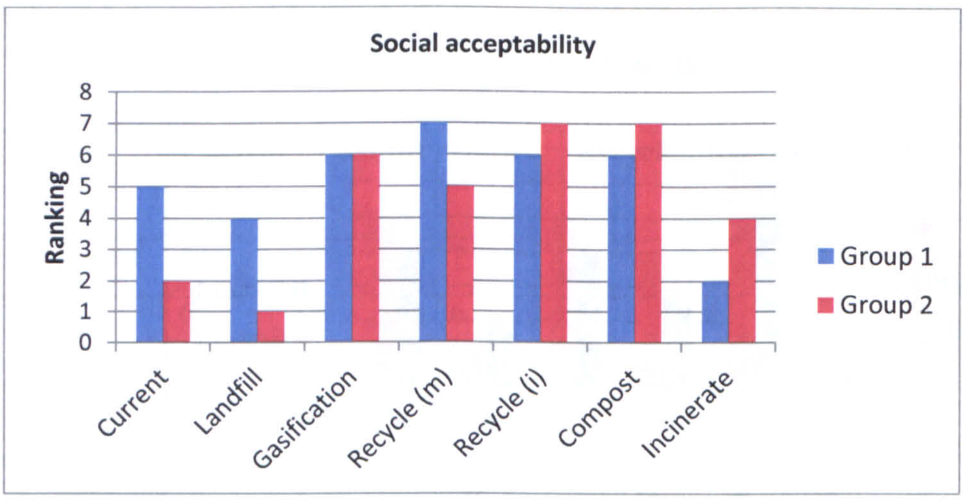

Figure 9.5. Ranking of waste management options in terms of social acceptability.

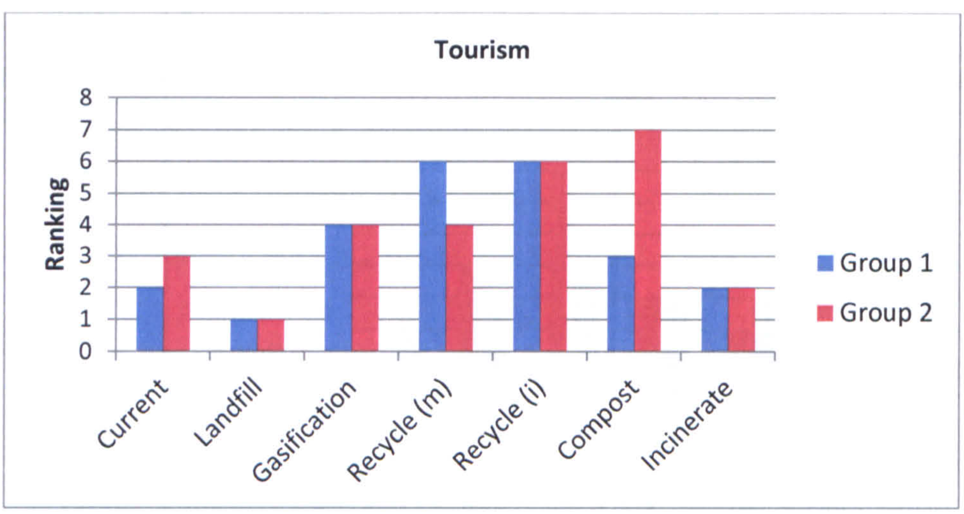

Figure 9.6. Ranking of waste management options in terms of tourism

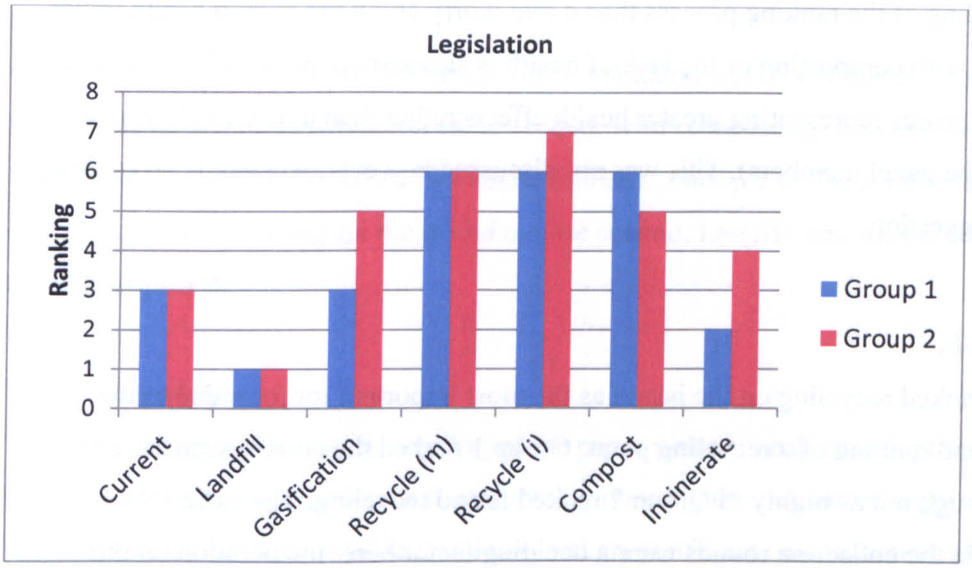

Figure 9.7. Ranking of waste management options in terms of legislation

From Tables 9.3 and 9.4 and Figures 9.1-9.7, it can be seen that the general patterns of ranking of the different options in terms of the social variables are similar. However, within the patterns there are noticeable variations and similarities, which are as follows:

9.5.1 Environmental health

The gasification of all paper waste ranks highest in terms of environmental health for both groups. Group 2 ranked composting as the lowest for environmental health, with landfill second lowest. Group 1 ranked composting and landfill equally low. The current scenario ranks next highest in environmental terms for Group 2. Group 1 ranked the current scenario in the middle. These results would seem to be due to the findings from WRATE described in the panel presentation.

9.5.2 Human health

Group 2 thought that all waste management options were equally beneficial for human health. This would tend to suggest that the members thought that any harmful emissions from the options were sufficiently well regulated to make them insignificant to human health. Group 1 ranked gasification of all paper waste as the best option for human health and composting as the worst. Recycling on the Isle of Wight was preferable to recycling on the mainland, due to the reduction in transport. The current scenario and all paper to landfill were of equal benefit. The high score for landfill and the low score for composting are surprising and possibly reveal more about the mixed understanding of the ranking process than a real worry about the human health issues associated with composting or the lack of health issues associated with landfill (with the higher scores representing greater health effects rather than a better option in the minds of the panel members). This was not discussed however, so there is no evidence for this suggestion.

9.5.3 Jobs

Group 2 ranked recycling on the island as the most important for jobs, due to the building and running of a recycling plant. Group 1 ranked the current scenario as the best, although not as highly as Group 2 ranked island recycling. The extra jobs involved in the collection rounds were a deciding factor here. Incineration on the mainland was the lowest for jobs from Group 1, as all the waste is collected in the general collection round and there are no island workplaces involved in the treatment process. Generally, island waste management processes were seen as more favourable for jobs than mainland processes.

9.5.4 Cost

The groups used the handout for the financial data presented in the introduction to rank the different options according to cost. Therefore the positions of the different paper waste management options are the same, but the magnitude of the scorings differ slightly.

9.5.5 Social acceptability

Group 1 ranked recycling on the mainland and composting as highest for social acceptability, due to the 'feel-good' factor and the lack of space and acceptability on the island for a recycling plant of its own. Recycling on the island and gasification also ranked highly with Group 1, again due to the 'feel good' factor of recovering energy and materials from waste. Incineration ranked lowest, as this is an option that historically has not been acceptable to the public. Group 2 ranked recycling on the island and composting as the best option for social acceptability. The current scenario was just above landfill as the lowest ranking for social acceptability by Group 2. This would tend to suggest a general public dissatisfaction with the current situation of waste management on the island.

9.5.6 Tourism

Group 1 chose both of the recycling options – mainland and island plants – as the best for the Isle of Wight. Gasification came second, with composting, incineration and landfill all seen as less beneficial for island tourism. Group 2 chose composting as the best option with recycling on the island a close second. Landfill and incineration were the worst options.

9.5.7 Legislation

The groups were agreed on the ranking of the paper waste management options as regards legislation – Recycling and composting rank highly, but surprisingly landfill, which is one of the most regulated and targeted areas of waste management, ranks at the bottom for both groups. Group 2 ranked gasification and incineration quite highly, but the current scenario got a low score. The ranking for legislation would tend to suggest that this particular social factor was difficult to score for.

As can be seen from the Tables and Figures, the two groups follow roughly the same pattern for their ranking of paper waste management options. Landfill and incineration were the two least popular options, with gasification and recycling on the Isle of Wight (i.e. the building of a local paper mill for the paper to be sent to) being the most popular options. Group 2 had a greater range of scores than Group 1, where all but landfill and incineration are relatively even.

9.6 Weighting and ranking combined

After the weighting and ranking discussions were completed, the two figures were combined (multiplied together) to give the waste management options a final score. The results are shown in Tables 9.5 and 9.6 on page 165.

The total scores for the different paper waste management options are shown graphically in Figure 9.8.

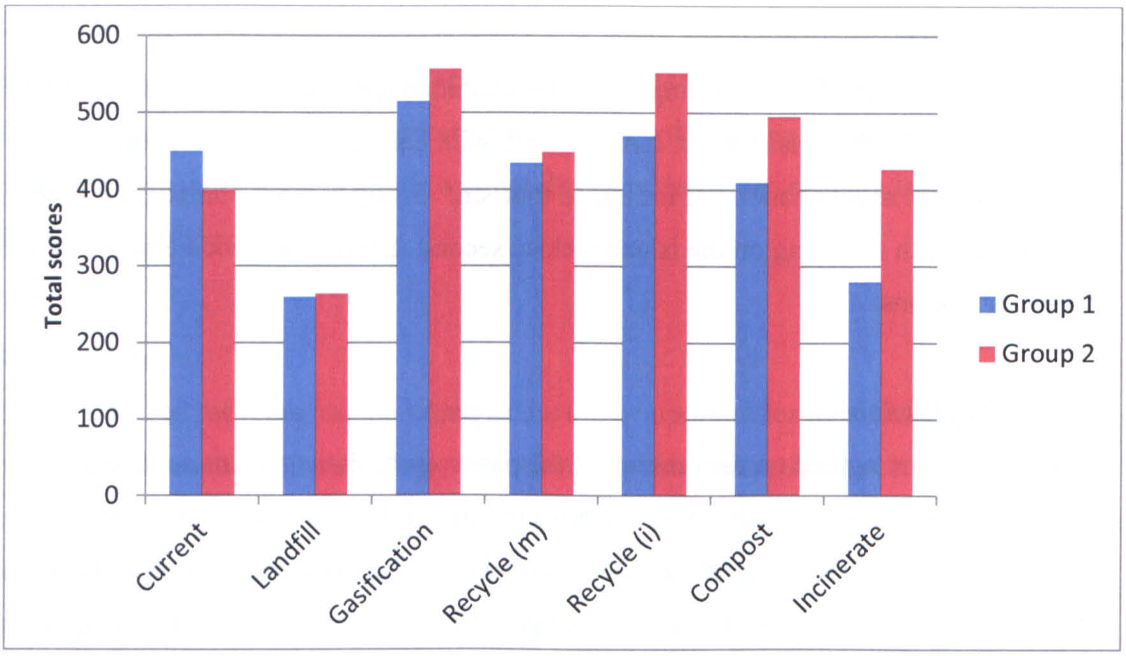

Figure 9.8. Comparison of the total scores for the different options. Group 1 and Group 2.

As with the total ranking scores, the combined ranking and weighting scores for both groups follow the same pattern. All waste paper to landfill is the option that scores least and all paper to gasification the highest, with the other options ranged between. The current option does not score as high as either all paper to gasification or all paper to be recycled on the island, but it is higher than recycling on the mainland for Group 1. Group 2 would rather send all paper to recycling on the mainland than have the current system. However, it should be noted that the issues surrounding the construction and running of a recycling plant on the Isle of Wight were not covered, either in the presentation or the discussions within the groups.

Options	Current	Landfill	Gasification	Recycle (m)	Recycle (i)	Compost	Incinerate (m)
Environment	4	2	6	3	4	2	4
Human health	5	5	6	3	4	2	4
Jobs	5	2	3	3	4	3	2
Cost	6	2	6	2	3	4	3
Acceptability	5	4	6	7	6	6	2
Tourism	2	1	4	6	6	3	2
Legislation	3	1	3	6	6	6	2
Total	450	260	515	435	470	410	280

Table 9.5. The scoring of paper waste management options on the Isle of Wight. Group 1.

Options	Current	Landfill	Gasification	Recycle (m)	Recycle (i)	Compost	Incinerate (m)
Environment	6	3	7	4	5	1	5
Human health	6	6	6	6	6	6	6
Jobs	3	4	2	3	7	4	1
Cost	4	3	7	2	1	6	5
Acceptability	2	1	6	5	7	7	4
Tourism	3	1	4	4	6	7	2
Legislation	3	1	5	6	7	5	4
Total	400	264	557	449	552	496	427

Table 9.6. The scoring of paper waste management options on the Isle of Wight.

The difficulties local communities have in finding new landfill sites and the detrimental effects on the environment, human health and well-being were mentioned in the presentations and discussed by both groups. The detrimental effects of landfill sites have also been regularly reported on in the media. The general public are relatively knowledgeable about the need for other treatment methods and this has been reflected in the fact that landfill has been placed at the bottom of the ranking list.

The fact that gasification was ranked the highest was due to the technology already being on the island, without any negative public reactions or environmental problems. The panel members had a good understanding of the technology, due to regular reports in the local press (Isle of Wight County Press) and as a result of the workshop presentations and the ensuing discussions. The closing of the plant by the Environment Agency rather added to the panel's confidence in the technology being safe when it is functioning. The groups felt that the local plant also reduces transport emissions and costs, provides jobs for the local community and the recovery of energy added to the 'feel good' factor.

9.7 Summary and review of the MCDA process

As described in Section 4.5 of this thesis, the MCDA process should be able to identify a preferred option for paper waste management on the Isle of Wight, using a combination of tools and involving a variety of stakeholders in the decision-making process. The MCDA panel workshop identified the gasification of all paper waste on the island as the preferred option, with the local processing of the waste as an important factor in this choice. The panel approved of local waste management options to reduce transport and to reduce the cost of the paper disposal. The fact that both groups have drawn similar conclusions would suggest that their conclusions are relatively standard for other mixed groups in the same kind of situation. However, the panel workshop had a strict time limit and consisted of a relatively small group of people, being those who answered the request from the researcher. If the panel had had longer to work on the decision-making and other stakeholders had been involved (such as politicians) the findings might have been different. The particular time that the workshop is carried out might also have an effect on the results; for example, the economy of local communities varies over time and is an important factor in decision-making. It is therefore important to emphasise the limits of the panel research, whilst at the same time acknowledging the support the workshop gave to the research. The panel method cannot be used as a decision-making tool on its own, but it adds to the findings of the LCA and the financial investigation to make the research more reliable.

9.7.1. Panel member feedback

The feedback from the panel members at the end of the workshop was positive. It was generally felt that each member had been informed and educated by the introductory presentation and, equally important, were pleased to be involved in a decision-making process. One member said that she had had little knowledge of the waste paper management process prior to being involved with the workshop and would now think and act differently as a result, being more careful to recycle and separate waste in the future. The feeling of being involved in a decision-making process was highlighted positively by another member, who said he often felt that decisions were made without public involvement. It was agreed that stakeholder involvement should be a more frequent part of local community decision-making. A third panel member felt that the wide variety of the workshop members meant that discussions and ideas were presented from all walks of life, leading to a more comprehensive debate about the paper waste management issues and, thereby, stronger conclusions.

The general agreement was that the workshop had provided an opportunity for the panel members to express opinions and views about waste management, a process everyone is involved in, but few know much about.

9.7.2 Criticisms of the MCDA panel workshop

The panel was supplied with environmental and economic data from my own research, without the possibility of these facts being checked by the panel members. However, one of the panel members worked for the major waste management company which, through a subsidiary company, has the waste management contract on the Isle of Wight. She said that her company had researched into the financial and environmental factors affecting waste management and drawn similar conclusions to those put forward in the panel presentation. The following criticism could, however, still be raised:

- The waste paper management options to be ranked by the panel groups were decided in advance. There was therefore no scope for the groups to suggest their own management combinations or other possibilities.

- The findings of the Isle of Wight panel will be used in this research as an indicator of similar results in the other areas. However, panels in other areas and other countries might come to different conclusions about the ranking of waste options and the weighting of social variables.
- The approval of local waste management facilities is more likely within those areas where facilities have been established for a while. The introduction of new local facilities might not be so acceptable.
- The workshop lasted four hours and it could be argued that this was too short a time to assimilate all the facts and arguments involved in the MCDA process. However, with the need to get people involved in the workshop, it was felt that a whole day might limit many members from coming, so the shorter time-span was felt to be justified.
- The time frame limited the number of options and variables the workshop could cover. The debates had to be curtailed, to allow the process to finish satisfactorily, which meant that some discussions were not completed. This could affect the decisions each group arrived at.
- It could be advantageous, for a subsequent workshop to allow the members to decide the social criteria themselves. Each local area may have certain factors that weigh more heavily than others, which might be forgotten when selecting the criteria in advance.

9.7.3. Conclusions

The panel supported the use of local solutions to paper waste management above the sending of waste to the mainland for treatment. Both groups came to roughly the same conclusions, working independently of each other, but it would be valuable to repeat the workshop process in other areas, with a longer time frame and with larger groups and other stakeholders as discussed in Sections 9.7 and 9.7.2.

Chapter 10 Summary of the results of the financial, LCA and MCDA research

During this research, the legislation and waste policy targets in each case-study area were identified. Given that all three areas are bound by EU legislation (although Norway is not an EU member) it is not surprising that all three areas had broadly similar policies; landfill is actively discouraged (or banned) and recycling is given a higher place in the waste hierarchy than thermal recovery (incineration or gasification).

The cost of managing paper waste in each area was also established for several different scenarios. On the Isle of Wight and the Shetland Islands, landfill presented the lowest-cost option (£100 and £122/tonne respectively), but this has and will change with the introduction of the landfill tax, which will continue to rise in the future, meaning that landfill will not be the cheapest option in coming years. The cheapest non-landfill solution is gasification on the Isle of Wight and incineration in Shetland. In Norway, recycling has the lowest cost, with the lowest transport costs and processing gate fees. Norway has a ban on the land-filling of biodegradable wastes which rules out this option for paper waste. The most expensive option in the three communities was found to be recycling for the Isle of Wight and gasification for Shetland and Norway.

The research has demonstrated the significance of transport costs when waste is managed outside the community in all three cases. In the case of the Isle of Wight, 12% of the cost of recycling the paper on the mainland is accounted for in crossing the Solent and road transport to Kent accounts for a further 11% of the total cost. For Nordfjord and Shetland, transport accounts for 44% and 47% of the cost of remote management respectively. In Nordfjord, recycling shows a definite price advantage and the high cost of local incineration still justifies the expenditure of £39 per tonne to transport the waste to Sweden if incineration is to be carried out.

The use of WRATE for the LCA has been discussed in Section 4.4 and the choice of this model was due to the extensive data base used within the model for the LCA calculations and the fact that the Environment Agency had developed the model specifically for use in waste management planning. As the data base is the Ecoinvent LCA database – that WRATE, SimaPro and other LCA systems all use – the environmental results would be similar if the research had used one of these other tools. In addition, the results were made more effective due to the inclusion of choices for the waste management system, such as waste collection vehicle type, road transport vehicles and specific waste treatment plants.

The LCA modelling of the complete paper waste system did not give a clear-cut best option for the environmental impacts of managing paper waste in any of the areas; but the following conclusions can be drawn;

- On the Isle of Wight, landfill and composting gave the largest negative impacts (but in different impact categories) whilst gasification resulted in a reduction in each impact category. However, recycling proved better than gasification in the categories of acidification, eutrophication and human toxicity.
- In the Shetlands, composting proved be the worst option having greater impacts than landfill in every category. Recycling was the best option for eutrophication and human toxicity; incineration with heat recovery performed best in terms of climate change and resource depletion impacts and gasification had the best impact on aquatic eco-toxicity.
- The isolated nature of the communities does not greatly add to the environmental impacts (this is particularly so when comparing the whole waste system for the Isle of Wight and its geographic, but not isolated, neighbour Portsmouth). However, the large transport distances in Norway account for a significant contribution to acidification, eutrophication and human and aquatic toxicity. This is largely due to NOx emissions from the transport vehicles.

The lack of a clear-cut best option in terms of environmental impact and the emergence of landfill as the lowest cost option for the Isle of Wight have confirmed that establishing BPEO is not a simple task. The MCDA exercise was carried out in an attempt to identify a solution that was guided by the above findings, but also incorporated the more-subjective factors such as acceptance by the community, impacts on employment and tourism.

Although the priorities of the two sub-groups were slightly different, both groups selected gasification as the best option and local recycling as second best. Both groups ranked landfill as the worst choice by a significant margin.

Feedback from the MCDA group members was positive and supported the use of the workshop as a decision-making tool in conjunction with the financial and LCA research.

In conclusion, this research has demonstrated that carrying out cost and LCA modelling and using a local MCDA panel to assess the results is an effective tool for determining the BPEO for paper waste management in isolated communities, bearing the following points in mind:

- A larger panel with a greater variety of stakeholders could change the outcome. For example, politicians and councillors might rank the financial costs of a particular scenario higher than the present panel,
- A longer time frame for the workshop to allow a fuller discussion of the information and variables involved could provide other solutions to the problem of paper waste management than examined in the research,
- The panel being held in other geographical areas, where the local community might have different priorities and the local conditions might make other variables more important.

However, the BPEO for one particular community can be assessed and determined using the research techniques from this research and in addition to the research being used for paper waste management in geographically isolated communities, the techniques selected here could be used for the entire waste stream and for non-geographically isolated areas.

Chapter 11 Review of results in relation to research questions

This chapter will look back at the research questions and assess whether they have been answered by the research. Although the literature review confirmed that there is no universal definition of a geographically isolated area, the initial assessment of the three case study areas confirmed that they are isolated communities. All three areas have chosen different waste management solutions. The use of WRATE – a proven LCA tool (Burnley, Phillips and Coleman 2011) - to assess the environmental effects of the complete waste stream as well as the paper stream was important in finding out whether the current waste management options were the most beneficial environmentally.

11.1 Principal research questions

Can the Best Practicable Environmental Option for paper waste management in isolated communities be identified by applying MCDA techniques to legislative, environmental, financial and other relevant information?

This research has shown that it is not possible to find a single BPEO for all isolated areas because local circumstances need to be taken into account. However, the research has supported the idea that local solutions are preferable, avoiding transport to distant recycling and recovery processes. The financial and MCDA analyses show support for this, with the cost of paper waste management on the Isle of Wight lowest when using the local gasification plant or landfill, for the Shetland Islands it is the use of the local incineration plant and landfill and in Nordfjord it is recycling, which is the closest geographical option and thereby the cheapest (Tables 8.6-8.8). The transport across the geographical barrier is also financially significant. The MCDA panels supported the use of local solutions, to the point of being positive to building a paper mill on the Isle of Wight to allow an increase in recycling rates.

The research using WRATE to determine the environmental impacts of paper waste management has shown that this input into defining the best practicable environmental option is dependent on a number of variables:

- The use of gasification of paper waste to energy technology is advantageous if the power that is substituted is generated from oil, gas or coal. If hydro-power is substituted, then energy from waste has an overall increase in environmental emissions.

- In Nordfjord, where hydro-power would be substituted, waste to heat is advantageous in all environmental categories compared to waste to power.
- In the UK, waste to heat is advantageous in relation to resource depletion and climate change, whilst waste to power is better in the other categories. The choice between heat or power generation is dependent on local markets for heat, such as the existence of a district heating scheme in Lerwick. The price of power, including subsidies, could also affect the choice of incineration plant for a local community.
- The geographical barrier is not a significant problem environmentally, either for sea or road transport, although road transport should ideally be kept to a minimum.

Based on the WRATE modelling, the recycling of paper is the best option in all three study areas in terms of acidification and eutrophication because of reduced emissions of sulphur dioxide and NO_x. In the other environmental categories energy and heat recovery perform better. This is supported by the findings of Leach and Lucas (1996). It should be stressed that both energy and materials recovery are a far better environmental option than landfill for paper waste.

The cost analysis supports the use of recycling in Nordfjord and on the Isle of Wight, whereas for the Shetland Islands, the cost of transport to a recycling plant makes this option less advantageous.

BPEO needs to include the environmental, financial, social, legislative and demographic factors. The use of the MCDA panel workshop in the research allowed all these factors to be included. The panel members supported gasification for paper waste on the Isle of Wight and also the possibility of recycling if it was situated locally. The use of the MCDA panel to allow the inclusion of social factors in the research was demonstrated and the result was a tool which could provide a decision for paper waste management in geographically isolated areas and which could take into account a wide range of qualitative and quantitative factors.

This research has demonstrated the effectiveness of using MCDA to combine environmental, financial and social factors, but it must be recognised that these findings are based on a small panel of people working to a constrained timescale. Therefore, further research would be required to demonstrate that the panel's findings are representative of their community as a whole.

11.2 Subsidiary questions

1. *Should the examination of paper waste be as a part of integrated waste management of all waste streams, or can it be examined successfully on its own?*

The research has shown that paper waste can be examined successfully on its own. The results from the financial tool were not affected by the separation of the waste stream, as collection and transport costs are per tonne of waste disposed of, as are the treatment costs. The LCA research with WRATE gave similar answers for the complete waste stream, which could then be used as a baseline for the separated paper stream. As the two sets of environmental data were similar, it is possible to state that the use of WRATE to measure paper alone is valid. The MCDA workshop examined the paper stream and it was concluded that this was in fact easier than examining the complete waste stream, which would have had too many factors and variables for the panel members to consider. Thus, it can be concluded that the examination of the paper waste stream on its own, using the research tools from this thesis, has been successful.

It is recognized that the study of paper on its own is a simplification of any real scenario and it also meant that some options, such as composting, were therefore unrealistically poor as regards environmental performance. As a result of these findings it is recommended that extended research, with a longer time span and more MCDA panel meetings, could use the same technique to assess the complete waste stream.

2. *Would it be beneficial to have a waste management system which includes waste paper from industry and commerce?*

The research concentrated on domestic paper waste and therefore did not answer this question specifically. However, having concentrated on domestic waste paper, which is the most difficult source to collect, any collection of commercial or industrial paper waste would make the management option chosen even more viable, as quantities would be higher and in many cases (as with office paper) of better quality. Thus the results for domestic paper waste suggest that an inclusion of commercial and industrial paper waste would be beneficial. It would be valuable to extend the study using the same techniques as used here, to confirm this point.

3. *What are the specific economic problems for isolated communities and the management of paper waste?*

The main economic problems for isolated communities are the transport of waste across the geographical barriers, whether it is sea transport or road transport. The financial examination showed that transport together with gate fees were the deciding factors in the costs of a waste management option. For example, sea and road transport in the Shetland Islands increased the cost of recycling by over £110 per tonne.

Isolated communities are not able to take advantage of the economy of scale, which affect an area's possibility of building financially viable local treatment plants. This accounts for the high costs of recycling as discussed above. The Isle of Wight has overcome this problem to some extent by adopting the modular gasification technology, rather than attempting to scale down an incineration process.

4. *How does the increased separation at source of paper waste affect the BPEO of isolated communities?*

The research looked into the financial, environmental and social sides of waste separation. The collection of paper waste for gasification/incineration/landfill would be within the mixed waste, whereas for recycling it needs to be separated by the householders. Financially, the separation of waste is a lot more expensive than including paper in the mixed waste (£132/tonne rather than £22/tonne; Hummel 2002). The collection emissions would be slightly increased by the need for added collection containers, such as wheelie bins.

However, the EU Waste Framework Directive (2008) has set a target of 50% recycled municipal waste by 2020, which can only be achieved by increased kerbside collection of dry recyclables and therefore local communities will have to accept the increased cost of kerbside collections and include this target in future waste management decision-making.

Recycling is generally supported by local communities, as demonstrated by the MCDA panel. In addition, the need to use recycling boxes increases people's awareness of waste and its problems and benefits.

5. Could the techniques in this research help isolated communities to become more pro-active as regards the European Union's increasing demands for waste reduction and resource conservation as well as contributing to the sustainable use of paper resources?

The research techniques demonstrated here are valuable in identifying the best environmental option by the use of WRATE and the best social option using the MCDA panel. Combined with the financial model, which assesses the cost of each option, isolated communities can find the most sustainable use of waste paper resources. The modelling has enabled the factors that define an isolated community and influence its BPEO for waste to be clearly identified. For example, for the Isle of Wight, transport of materials to the mainland is environmentally insignificant, but has serious cost burdens.

In doing this, each community will necessarily be pro-active as regards targets and demands from the EU legislation.

6. Is there a viable market for recovered paper from isolated communities?

The research has shown that waste paper is a valuable resource for both energy recovery and recycling. For isolated communities, the decision has to be made whether to recycle paper, with its increased transport costs and minor environmental burdens, or to use paper for energy recovery. This latter option has the added advantage of there always being a local market for power or heat.

As stated above, the choice between energy recovery or the recycling of paper waste is not clear cut. However, in all study areas both treatment options were far better than sending paper to landfill, supporting the use of energy and material recovery for geographically isolated areas.

Chapter 12 Conclusions and Recommendations

12.1 Conclusions

This research has provided geographically isolated areas with a method and a tool to assess and address the specific waste management requirements such areas have in relation to economic, environmental, legislative and social variables. The research showed the need for a holistic examination of isolated communities and waste management and examined the specific requirements for paper waste management. Furthermore, it was shown that there has been a lack of the combined use of financial, LCA and MCDA techniques in the literature, assessing the particular needs of isolated areas when making decisions about the optimum techniques for their paper waste. This research has addressed that need, enabling BPEO to be used in paper waste management decision-making.

The use of the MCDA panel demonstrated that, in principle, local communities could use this technique to include stakeholders in waste management decision-making, assessing information in different categories and helping to determine the BPEO for that specific community.

The research has shown that isolated communities do have specific issues in regard to paper waste management, the most important of these being the financial and social costs of transport away from the area and the environmental burdens of different waste treatment options. The significant transport costs involved in crossing geographical barriers support the use of local solutions determined by the MCDA panel. It was shown that, environmentally, the best option is dependent on the fuels displaced by energy recovery options.

The research tool is valuable in allowing such communities to decide on the most sustainable waste management option, taking into consideration as many factors as possible.

The tool developed here is transparent and easy to use for non-experts, thereby making it available to all sectors of a local community and any stakeholders who wish to be involved in the decision-making process. Specialist knowledge is however necessary to generate the LCA outputs and provide general guidance to the MCDA panel.

The best environmental option has been shown to be power or heat recovery from paper waste in regards to resource depletion and climate change, whereas recycling is the better option in regards to acidification, aquatic eco-toxicity, eutrophication and human toxicity.

12.2 Recommendations

It is recommended that further research is required in the following areas:

- Extending the use of MCDA panels, in the time used for the panel workshop, the number of panel members involved, the types of stakeholders attending and in the stage of the research in which they are involved. A lengthened workshop would allow research into the complete waste stream and the involvement of the panel at an earlier stage in the investigation may influence the decisions made.
- Repeat the MCDA work in other isolated communities.
- Further comparisons between geographically isolated areas and their closest mainland communities.
- Further research is required into the environmental benefits of the incineration of paper waste with the recovery of power versus the recovery of heat.
- Further research is required into methods to reduce aquatic eco-toxicity in paper recycling.
- Devise methods to include factors such as noise, smell, effects on biodiversity in the decision-making process.
- Further investigation of the limitations in the use of WRATE (as outlined in Section 8.7).

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